DRAFT

Water Quality Assessment

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Table of Contents

1. Introduction

Water quality is a major concern during the restoration of the Greater Everglades. Water quality deals with both the physical properties and chemical constituents of both surface and groundwater. The water quality at any given location is dependant on many factors that are often interrelated. One of the most important factors effecting water quality in the Greater Everglades is the source of water. The delivery and routing of water from other sources through the Central and Southern Florida project to Everglades National Park (ENP) is controlled and regulated. With the changes in water deliveries imposed by the Interim Structural and Operational Plan/Interim Operational Plan (ISOP/IOP), Congress specifically expressed concern for how the altered water delivery schemes could impact the quality of water delivered to ENP.

The first analysis evaluated all water quality variables at select structures and inflow points of ENP in order to determine which groupings of water quality variables had significant changes during ISOP/IOP. We used a simple statistical test on many of the variables (comparing pre-ISOP/IOP vs ISOP/IOP) to characterize water quality in order to determine if there were changes in these variables during ISOP/IOP.

Historically, the macronutrient, phosphorus (P) is the water quality variable that has drawn the most attention. This nutrient limits Everglades ecosystem productivity and biomass accumulation. The Everglades ecosystem has developed under extreme low levels of total phosphorus. Excessive levels of total phosphorus (TP) causes anthropogenic eutrophication that is characterized by increased productivity, reduced dissolved oxygen, changes in species composition, and reduced biodiversity. Stormwater discharged from the Everglades Agriculture Area (EAA) and urban areas have elevated levels of TP and when the stormwater is discharged into the Everglades, it impacts Everglades ecosystems. The severity and extent of these impacts on A.R.M. Loxahatchee National Wildlife Refugee (LNWR) and ENP caused the federal government to sue the State of Florida in 1988 for not enforcing its water quality laws. The lawsuit was settled in 1991 (Hoeveler, 1991), and the resulting State/Federal Consent Decree established TP criteria for inflows to the LNWR and ENP

How ISOP/IOP impacted the delivery of TP loads and concentrations is of prime concern to ENP. ENP expected some water quality changes during ISOP/IOP. First, TP concentrations at SRS inflow structures should decrease because four Stormwater Treatment Areas (STA) were functioning upstream of WCA-3A during ISOP/IOP. Second, there also might be an increase of TP concentrations at L-31N/C-111 structures

from ISOP/IOP flows because historically, SRS flows have higher TP concentrations than L-31N/C-111 flows. However, it was expected that the C-111 detention areas would function as a (periphyton) STA and remove excess TP from ISOP/IOP deliveries from SRS to Taylor Slough and the Eastern Panhandle of ENP. The second analysis is a statistical and graphical assessment of pre-ISOP/IOP vs ISOP/IOP on flows, total phosphorus concentrations and loads at structures and sites, located in and around Water Conservation Area 3A (WCA-3A), ENP Shark Slough, and ENP Taylor Slough and the Eastern Panhandle to determine if the above water quality expectations were real.   Also, the performance of the C-111 detention areas was evaluated in terms of TP removal using both the actual data and the Dynamic Model of Stormwater Treatment Areas (Walker and Kadlec, 2002). Finally, impacts of ISOP/IOP on Consent Decree compliance in terms of inflow TP concentrations to ENP are reviewed.

The final expectation is that discharges into ENP would not cause increases in TP concentrations in surface water, groundwater and soils in ENP marshes. To determine if this is true, the results of monitoring wetland ecosystem characteristics of downstream areas of the southern Everglades before and during ISOP/IOP are presented. These analyses are followed by a section of recommendations on future operations, and a section of recommendations on future monitoring and assessment in areas where information or understanding is lacking.

2. Assessment on IOP on All Water Quality Variables

Water quality issues encompass both the physical properties of water and the chemical constituents of the Everglades surface and groundwater. These variables are often grouped into five general categories; they are physical properties, nutrients, major ions, trace metals, and pesticides. To assess the impact that the water-delivery changes had on the quality of water entering the ENP, a statistical test was designed. The test compared the mean concentration of water constituents before and after ISOP/IOP.

Water-quality data for the statistical analysis were obtained from the South Florida Water Management District's database (DBHYDRO). Stations selected for the analysis are at the northern and eastern boundaries of the Park, where most of the flow enters the ENP. These stations are shown in Table 1. A few of the stations, that did not have enough water-quality data, were removed (N) from the analysis. The five general categories, physical properties, nutrients, major ions, trace metals, and pesticides were tested.

A two-tailed T-Test was used to compare the concentration of water-quality constituents before and after ISOP. If the difference of the means reached a significance level of 5-percent, the difference was considered *significant*; if the significance level was between 5 and 10-percent, the difference was considered *probable*. Although the T-Test is a reasonable procedure for comparing the means, the test did not account for hydrologic changes—such as changes in precipitation—which could impact the water-quality concentrations.

Table 1. Water Quality Stations

ID	LOCATION	T-TEST
S-12A	On levee L-39, at WCA-3A	Y
S-12D	On levee L-39, at WCA-3A	Y
S-176	On C-111, north of C-113	Y
S-177	On C-111, SR-9336	Y
S-178	On C-111E, SR-9336	N
S-18C	On C-111, South of SR-9336	Y
S-331	Pump station,	N
S-332	On L-31W, at Taylor Slough	Y
S-332D	Pump station,	N
S-332DW	Downstream of S-332D	N
S-333	On L-29 Canal, at WCA-3A	Y
S-334	Gated Culvert	N

To account for variations in hydrologic conditions, two time series were used in the analysis: a long series, which includes the whole historical record, and a short series, which starts in January 1997 and extends to the end of record. By using the short series, it is assumed that the 1997-99 (before ISOP) and 2000-01 (after ISOP) periods had similar hydrologic characteristics and that each period had similar effects on the water-quality concentrations. In interpreting the T-Test, results from the short time series were considered more relevant and were given more emphasis in the final analysis. Because the T-Test did not distinguish between positive or negative differences (two-tailed test), the results do not specify whether the concentrations increase or decrease during the ISOP. From the T-Test results, it is only known that means are significantly different. By using time series plots, it was found that most concentrations increased after ISOP—dissolved oxygen was an exception.

The results of the T-Test are summarized in Table 2. The maximum number of variables available for analysis was about 250, per station; the number of variables tested ranged from 37 to 192; and the percentage of variables passing the test ranged from less than 1 to 52 percent. To facilitate the analysis, considering the large number of parameters available, variables were grouped into five classes: physical/chemical properties, nutrients, major ions, trace metals, and pesticides.

Table 2. Results of the T-Test analysis.

		S-12A	S-12D	S-176	S-177	S-18C	S-333	S-332
Variables	Tested	37	38	123	124	192	37	122
	Passed	9	3	62	20	1	6	64
		Passed T-Test (Y) ---------------- Failed T-Test (N)						
Physical Properties		Y	N	Y	Y	N	N	Y
Nutrients		Y	Y	Y	Y	N	Y	Y
Major Ions		N	N	N	Y	N	N	N
Metals		N	N	N	Y	N	N	N
Pesticides				Y	N			Y

Physical Properties. The variables considered under physical properties were temperature, dissolved oxygen, specific conductance, color, and turbidity. If at least three of the variables passed the T-Test, at the 5-percent significant level, it was assumed that the ISOP had affected the physical properties of the water delivered to the ENP.

Nutrients. This group includes nitrate, ammonia, and total phosphate. If two of the variables passed the test, at the 5-percent significant level, it was assumed that ISOP had affected the concentration of nutrients.

Major Ions. Most of the variables in the water quality database were major ions. For the analysis, the major ions group includes calcium, sodium, potassium, sulfate, and chloride. If three of the ions passed the T-Test, at the 5-percent significant level, it was assumed that ISOP had affected the concentration of major ions.

Trace Metals. The metals selected for the analysis were mercury, zinc, lead and copper. If three of the metals passed the test, at the 5-percent significant level, it was considered that the ISOP had affected the concentration of trace metals.

Pesticides. The database includes more than 150 pesticide compounds. For the T-Test analysis, if 10 or more compounds passed the test, if was assumed that the ISOP had affected the concentration of pesticides.

The results of the T-Test indicates that:

1. Except for S-18C, stations tested appear to have been affected by ISOP. The variables more often affected were those grouped under physical properties and nutrients, and the least affected were those under the major ions group.

2. General comparison of results between stations was avoided. Stations did not always have the same sampling methodology and number of variables. Comparison of specific variables between stations, however, was possible.
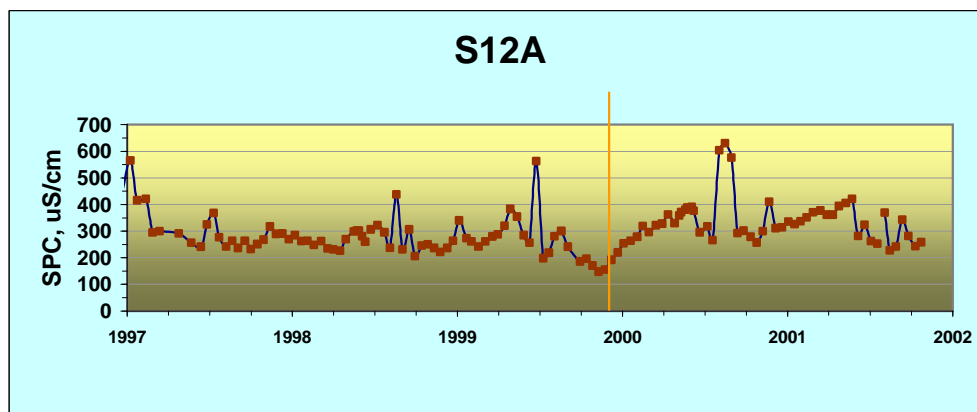
S12A

3. At station S-12A, ISOP affected mostly the physical and nutrient groups. This station did not have enough pesticide data for analysis.

4. At station S-12D, ISOP affected mostly the nutrient group. This station did not have enough pesticide data for analysis.
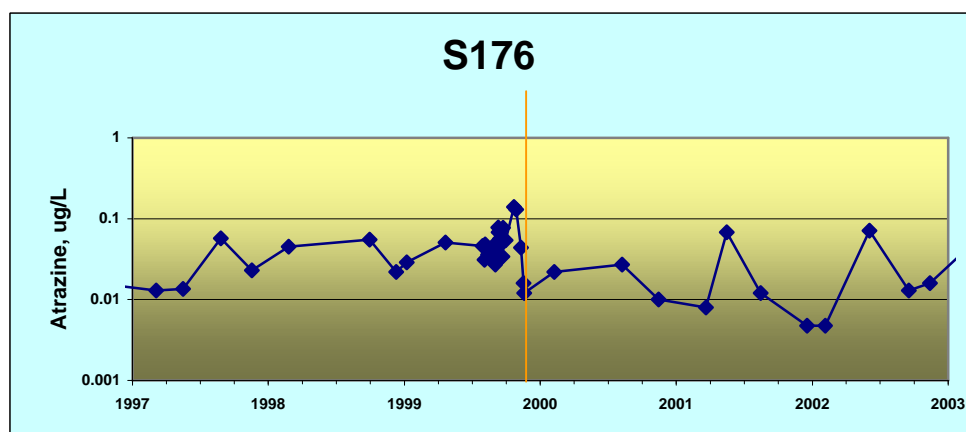
S176

5. At station S-176, ISOP affected mostly the pesticide group. The figure above shows that atrazine decreased after ISOP.

6. At station S-177, ISOP affected mostly the physical property and major-ions group.
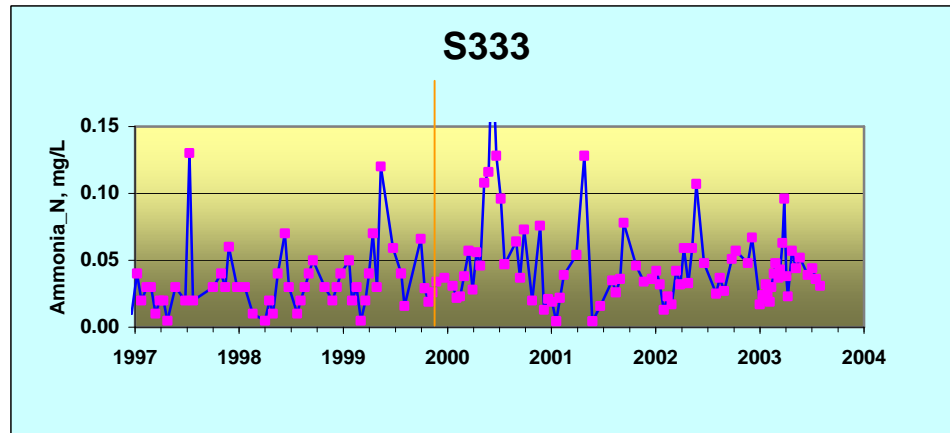
7. At station S-18C, nearly all of the variables failed to pass the T-Test, suggesting that ISOP did not affect the quality of the water. For the variables that passed the T-Test, the records were not long enough for a valid analysis. Thus, it was considered that ISOP did not affect this station.

8. At station S-333, only few of the variables from the physical and nutrient groups passed the T-Test. It was conclude, however, that ISOP only affected the nutrient group.

9. At station S-332, ISOP affected the physical, nutrient, and pesticide groups; the majority of the variables that passed the test were from the pesticide group.

10. The two most common problems throughout the analysis were that:

    (a) The stations did not have data or that the period of record was not long enough for a valid analysis, and;
    (b) Concentrations below the detection limit were set to a negative value; however, this limit was not always constant—even for the same constituent.

11. The preliminary results of the T-Test suggest that ISOP had affected the quality of the water delivered to the ENP.

3. Assessment of the Interim Operational Plan: Phosphorus Concentrations and Loads

Changes in the spatial and seasonal distribution of inflows to ENP were made in 1999 to preserve habitat for the Cape Sable Seaside Sparrow (CSSS), an Endangered Species nesting in the Park. The "Interim Structural and Operational Plan" (ISOP) in 1999 and "Interim Operational Plan" in 2002 (IOP) followed a long series of regional water-management schemes tested since the 1960's to deliver flow to ENP while providing flood control and water supply benefits to urban and agricultural areas in south Florida.

The last major change was made in 1987, when operations evolved from a flow-thru mode, with inflow structures along the Tamiami Trail left open, into a rainfall-driven mode, with inflow structures regulated based upon antecedent rainfall in Water Conservation Area 3A (WCA-3A) in an attempt to restore natural flows and hydroperiods. ISOP/IOP measures to protect the CSSS habitat and contemporaneous changes in regional water management (e.g., initial phases of the C-111 buffer project) may have had secondary (positive or negative) impacts on ENP hydrology, water quality, vegetation, and wildlife.

This analysis evaluates changes in phosphorus concentrations and loads at structure sites located in and around WCA-3A and ENP following implementation of the IOP (term used below to represent both ISOP & IOP). Nutrient enrichment is a major regional concern because of documented impacts on water quality and ecological communities (SFWMD, 2003). Changes potentially attributed to the IOP are assessed in the context of other variations associated with climate, other changes in water management, and water quality trends in basins discharging into WCA-3A, the immediate source of flow discharged into ENP's Shark Slough.

The analysis is based upon hydrologic and water quality data collected primarily by the South Florida Water Management District (SFWMD) between 1994 and 2003 (Figure 1). A relatively simple statistical procedure is applied to identify monitoring sites where changes in average flows, concentrations, or loads are likely to have occurred following IOP implementation in late 1999. The procedure accounts for background variations associated with rainfall. More detailed analyses and interpretations of the results are performed on a regional basis to further describe the changes and assess the likelihood of causal linkages to the IOP, as opposed to other anthropogenic or natural factors. Three regions are considered: WCA-3A, Shark Slough, and the Taylor Slough/Eastern Panhandle basins. Results are discussed in relation to compliance with ENP inflow P concentration limits specified under the State/Federal consent decree (Hoeveler, 1991). Recommendations are made with respect to future operation, monitoring, and assessment.

Supporting data are summarized and graphed in the Appendix. Further details on the data compilation and statistical analyses are posted at http://www.wwwalker.net/iop .
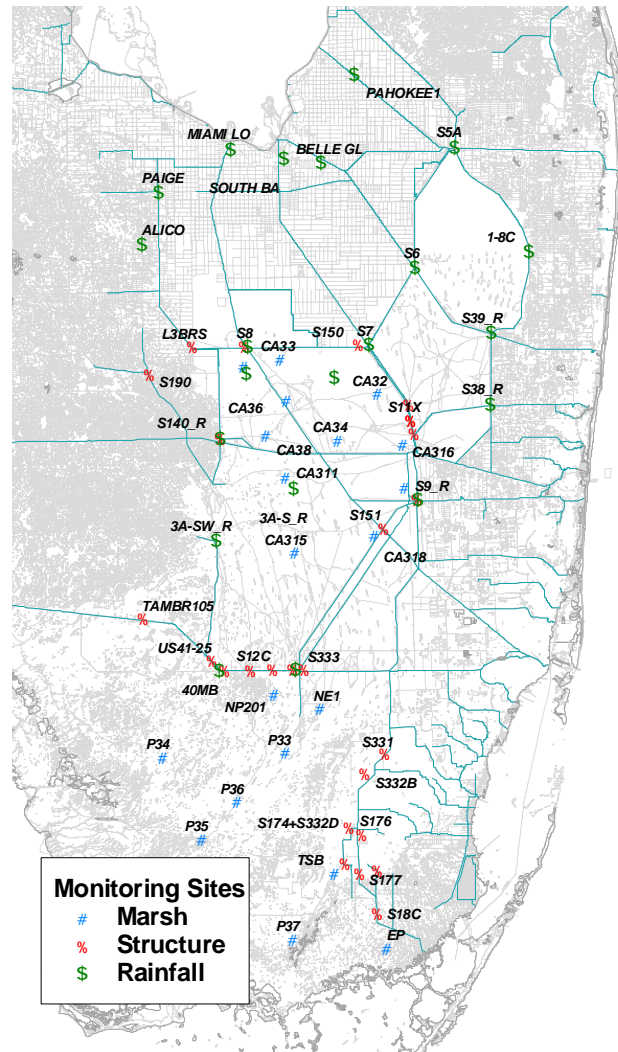
Figure 1. Monitoring Sites.

3.1 Data Compilation

Variations in WCA-3A stage and basin rainfall between 1984 and 2003 are shown in
Figure 2. These are two of the primary factors controlling the water budget of WCA-3A
and discharges into Shark Slough. Basin rainfall is an average of data from monitoring
sites located in and around the WCA's, EAA, and C-139 basin (Figure 1). This region
represents most of the "watershed" above the S-12/S-333 inflow structures to SRS.

Figure 2. WCA-3A stage and rainfall.   Stage is average of 3 stations (Sites 63, 64, 65). Rainfall is a spatial average of sites identified in Figure 1. Arrows show pre-IOP (June 1993- May 1999) and IOP periods (June 1999 – May 2003) selected for the analysis.

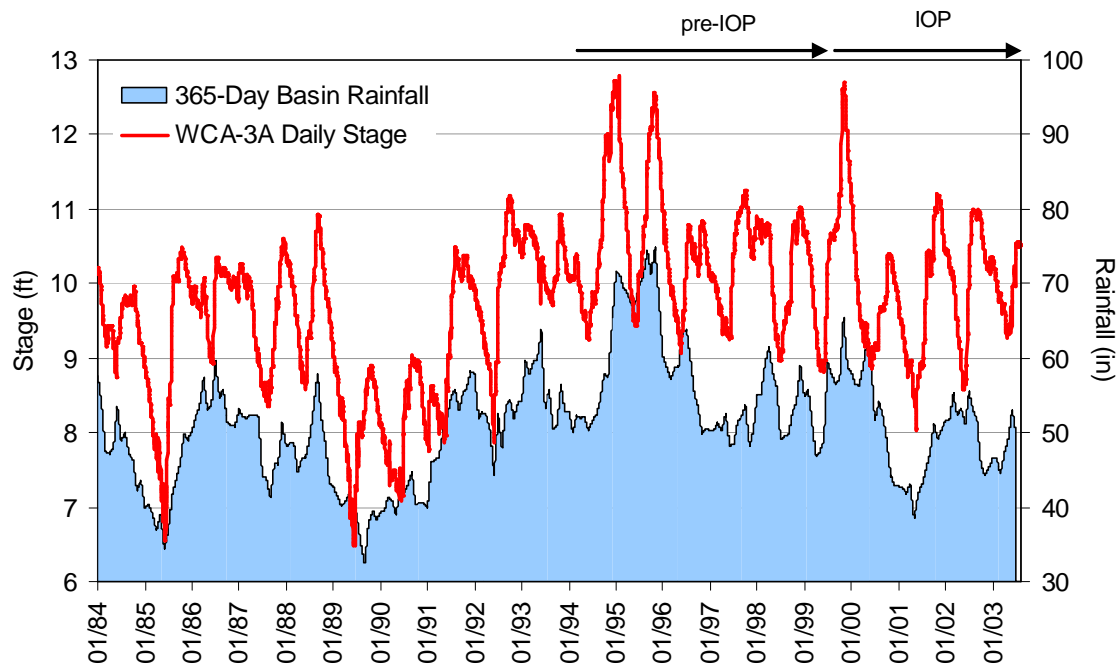Changes potentially attributed to the IOP have been identified by comparing data from the 1994-1999 and 2000-2003 periods. Rainfall ranged from 50-70 inches/year in the pre-IOP period, as compared with 40-60 inches/year in the IOP period. Because of the difference in rainfall regimes, effects of IOP cannot be assessed by a direct comparison of monitoring data from the two periods.   Adjustment for rainfall variations is essential to distinguish long-term changes potentially related to IOP from short-term climatologic variations.

Data prior to 1994 are less relevant as a frame of reference for evaluating IOP impacts because regional water management schemes were not typical of subsequent years and WCA-3A, in particular, was regulated at lower water levels. Best Management Practices (BMP's) implemented in the EAA during the mid 1990's reduced phosphorus loads to the WCA's (SFWMD, 2003). These reductions may have influenced phosphorus concentrations and loads at ENP inflow structures. Focusing on the 1994-2003 post-BMP period enables separation of potential BMP and IOP effects. As demonstrated below, there were no apparent trends in phosphorus loads from EAA structures into WCA-3A or into WCA-3A as a whole over the 1994-2003 period, although there were apparent trends in loads from specific sources outside of the EAA (increasing at S9 and S-140, decreasing at the S-11's and G-155).

Phosphorus concentration data collected at canal and marsh sites are derived from SFWMD's long-term water quality monitoring network (Figure 1). Concentrations were

measured in grab samples collected biweekly at structures and monthly at marsh sites. Weekly flow-proportional composite samples were typically collected at pump stations and supplemented with grab samples. Phosphorus concentrations below the detection limit (2 – 4 ppb) have been set equal to the detection limit prior to computing loads and performing statistical analyses. Results are subject to limitations associated with laboratory phosphorus analyses in the low concentration range (< 10 ppb), including (a) expected low precision of individual sample results at values approaching the detection limit; (b) possible negative bias in the data during portions of 1996 and 1997, as identified under Florida Department of Environmental Protection's (FDEP) Everglades Round Robin program (Walker 1999); and (c) decrease in detection limit from 4 ppb to 2 ppb in 2002, which may have influenced comparisons of data from the pre-IOP and IOP periods.

Water quality data supplied by the U.S. Army Corps of Engineers Jacksonville District (Anamar Inc. et al. 2003) are based upon daily composite, weekly composite, and/or grab samples collected at structures and pump stations in the L-31N/C-111 basin between 2001 and 2003. Because of the limited period of record, these data are used to evaluate concentration dynamics in detention areas associated with the C-111 buffer project, but not in comparisons of the pre-IOP and IOP periods.

Daily flow data have been obtained from regional databases (SFWMD's DBHYDRO and ENP's FOREVER). Figure 3 shows water year (June-May) flow time series at gauging sites in Shark Slough and the L31N/C-111 basin.   Flows are plotted on the same scale at each site. This provides general perspective on spatial and temporal variations in flow during the study period.
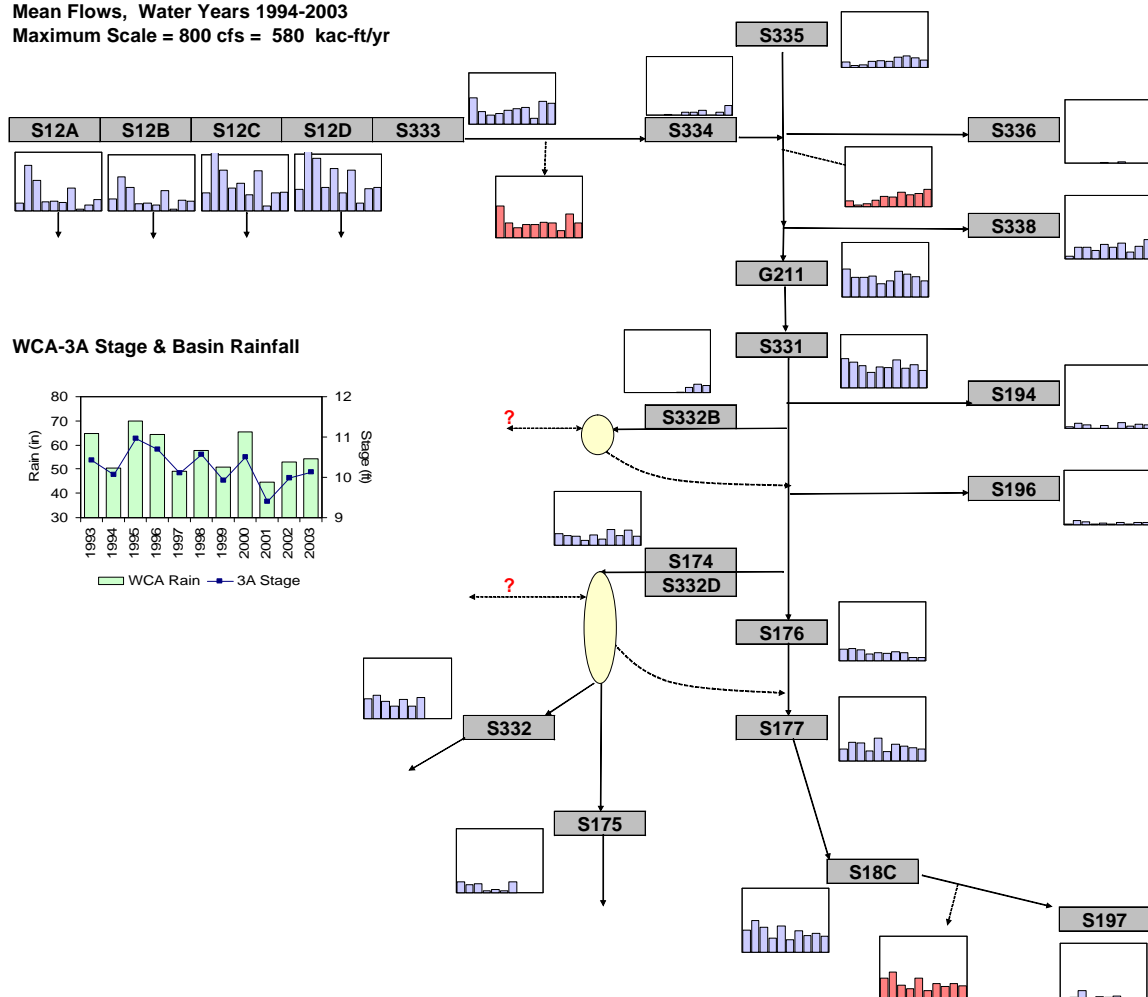
Figure 3. Spatial and Temporal Distribution of Flow. Water Years 1994-2003. Scale maximum = 800 cfs = 580 kac-ft/yr for each structure. Values in red are computed by difference from measured flows at other structures.

Flow and concentration data have been integrated to produce daily time series of phosphorus concentrations and loads at each monitored structure or pump station where both flow and water quality are monitored. The integration has been performed by interpolating concentrations between adjacent grab-sampling dates with positive flow. When available, weekly flow-weighted composite samples have been used in place of grabs. Daily flows and loads have been summed on monthly and yearly bases to support statistical modeling of IOP effects. Several composite flows are computed by combining results from individual structures. For example, the 'S-12'X term is the sum of values from the individual S-12 structures. Table 1 defines the individual and composite structures and lists average flows, concentrations, loads in the pre-IOP and IOP periods

Table 1. Observed Means by Structure and Time Period.   Conc.= arithmetic mean of yearly flow-weighted means concentrations. FWC = mean load / mean flow for each time period.

	pre-IOP (1994-1999) Means				IOP (2000-2003) Means				
	Flow	Load	Conc	FWC	Flow	Load	Conc	FWC	
Structure(s)	kac-ft/yr	kg/yr	ppb	ppb	kac-ft/yr	kg/yr	ppb	ppb	Description
WCA-3A Inflows									
G155	112	25380	188	184	37	9585	191	208	G155 Outflow to NW WCA-3A
S8+G404	374	44183	94	96	282	32126	85	92	Outflow from Miami Canal to NW WCA-3A
S150	50	3469	59	56	44	2876	52	54	S150 Outflow to NE WCA-3A
S190	89	13075	113	120	77	9722	109	102	S190 Discharge to Westerm WCA-3A
S140	134	6464	40	39	119	10119	74	69	S140 Discharge to Western WCA-3A
S11X	634	19828	28	25	353	10582	22	24	WCA-2A Outflow to WCA-3A: S11A+B+C
S9	243	4225	14	14	255	6774	22	22	Discharge from C11W Basin to WCA-3A
WCA-3A IN	1635	116624	57	58	1167	81784	55	57	Total Inflow to WCA-3A
ENP Shark River Slough									
S12A	183	1413	7	6	103	1263	10	10	S12A from WCA-3A to ENP Shark Slough
S12B	155	1211	6	6	109	1027	8	8	S12B from WCA-3A to ENP Shark Slough
S12C	315	2723	7	7	209	2062	9	8	S12C from WCA-3A to ENP Shark Slough
S12D	396	4054	9	8	240	3147	11	11	S12D from WCA-3A to ENP Shark Slough
S12X	1050	9401	8	7	661	7499	10	9	WCA-3A Outflow to ENP Shark Slough: S12ABCD
S333	165	2321	11	11	186	3129	14	14	S333 from WCA-3A to NESRS & S334
S12X+S333	1215	11722	8	8	847	10628	11	10	Shark River Slough Total: S12X + S333
NESRS	155	2099	11	11	144	2559	14	14	Net Inflow to Northeast Shark Slough: S333-S334
SRS_ENP	1205	11500	8	8	804	10058	11	10	ENP Shark Slough Total = S12X + NESRS
Taylor Slough / Eastern Panhandle									
L31N_IN	60	1039	12	14	139	2232	13	13	Net Inflow to L31N from North: S334+S335-S336
S174+S332D	91	1039	9	9	133	1558	9	9	Outflow from L31N to L31W/ S332D Detention Area
S332+S175	219	1982	7	7	75	726	7	8	L31-W Direct Outflow to Taylor Slough
S176	92	1125	10	10	56	615	8	9	S176 on C111 Canal
S177	137	1147	7	7	127	1643	10	10	S177 on C111 Canal
S18C	200	2871	11	12	166	1541	7	8	S18C on C111 Canal
S18C-S197	165	2129	10	10	142	1254	7	7	Inflow to ENP Panhandle from C111: S18C - S197

For consistency with hydrologic and biological IOP assessments being conducted independently, annual totals have been computed on a water-year basis (June – May; i.e. Water Year 2003 extends from June 1, 2002 through May 31, 2003). This convention roughly separates the annual hydrographs so that the wet season starts at the beginning of each water year. Water years 1994-2003 extend from June 1,1993 through May 31, 2003. Repeating the analysis with a May-April water year definition (used for tracking BMP performance in the EAA) does not influence the basic conclusions.

The flow, concentration, and load data are summarized and plotted in the Appendix.

3.2 Screening Procedure

Shifts in mean flow, concentration, or load have been identified by comparing yearly data before and during IOP using graphical and statistical techniques. Identifying changes specifically related to IOP is difficult in the presence of background variability attributed to variety natural and anthropogenic factors, as well as to sampling variability. Background variance in structure flows and TP loads is correlated with basin rainfall at most structures. A regression model of the following form has been used as a screening procedure to test for shifts in the long-term mean between the two time periods in the presence of natural variations associated with rainfall and other random factors:

$$Y = B_0 + B_1\,\text{Rainfall} + B_2\,\text{IOP} + \text{Error}$$

where,

Y = response variable (water year flow, load, flow-weighted-mean concentration)
Rainfall = basin average rainfall (inches)
IOP = dummy variable (= 0 before IOP, = 1 during IOP).
Error = random variance attributed to sampling and other factors

The rainfall term represents year-to-year variations in Y that are correlated with rainfall. The IOP term represents a hypothetical shift in the mean value of Y after IOP implementation. While the model accounts for correlations with rainfall, it does not require such correlations to be present. If $B_1=0$, the model condenses to a direct comparison of pre-IOP and post-IOP means, similar to Student's t-test applied directly to the observed values (Snedecor & Cochran 1989).

The likelihood that a shift in the long-term mean occurred after IOP implementation is assessed by testing a two-tailed null hypothesis ($B_2 = 0$) using the mean and standard error of B_2 and the degrees freedom associated with the regression (10 years - 3 coefficients = 7). Apparent differences in the mean are classified as follows: (1) not significant ($p > 0.15$); (2) mildly significant ($p = 0.05 – 0.15$); (3) significant ($p < 0.05$). Because the p levels used to define these categories are somewhat arbitrary, the categories are used for summary and display purposes only. For a one-tailed null hypothesis, the quantity p/2 estimates the probability that the true change was in the opposite direction from the apparent change indicated by the sign of the regression

coefficient. For example, with $B_2 > 0$ (indicating an increase under IOP) and $p = 0.20$, there would be a 10% chance that mean actually decreased.

Classification of a result as "not significant" indicates that any change that may have occurred in the long-term mean was not large enough to be detected in the presence of background variations. It does not prove that no change occurred. Similarly, classification of a result as "significant" indicates that a change in the mean value probably occurred between the two periods.   Any causal linkages to IOP would be drawn from further analyses and interpretations.

The model allows adjustment of the observed time series to account for rainfall variations:

$$\text{Adjusted Y} = \text{Y} + B_1 \, (\text{Mean Rainfall} - \text{Yearly Rainfall})$$

The mean rainfall (54 inches/yr) is computed for the entire 1994-2003 period. Differences between the IOP and pre-IOP periods are expressed in absolute terms (B2) and as a percentage of the pre-IOP, rainfall-adjusted mean.

A simpler procedure for identifying differences between pre-IOP and IOP means is to regress the response variable against rainfall for the pre-IOP period only. The regression model is subsequently applied to the IOP period and differences between observed and predicted values (residuals) reflect potential IOP effects. Unlike the above regression model, this procedure does not assume that the regression slope for rainfall (B_1) is constant. While formal hypothesis tests are not performed, this simple graphical technique has been used as an exploratory tool to supplement the multiple regression analyses.

Figure 4 demonstrates application of the screening procedure to data for the combined outflows from WCA-3A to Shark Slough (S-12X+S-333). The utility of basin rainfall as an index of regional hydrologic variability is supported by the fact that the model explains 94%, 82%, and 82% of the variance in the observed outflows, loads, and concentrations, respectively. Results indicate that mean concentration was significantly higher during the IOP period by 1.9 ppb or 22% ($p = 0.02$).   The result is confirmed by the fact that the pre-IOP regression vs. rainfall underestimates the observed concentrations in each IOP year.   Apparent changes in mean flow (decrease) and load (increase) are not significantly different from zero.
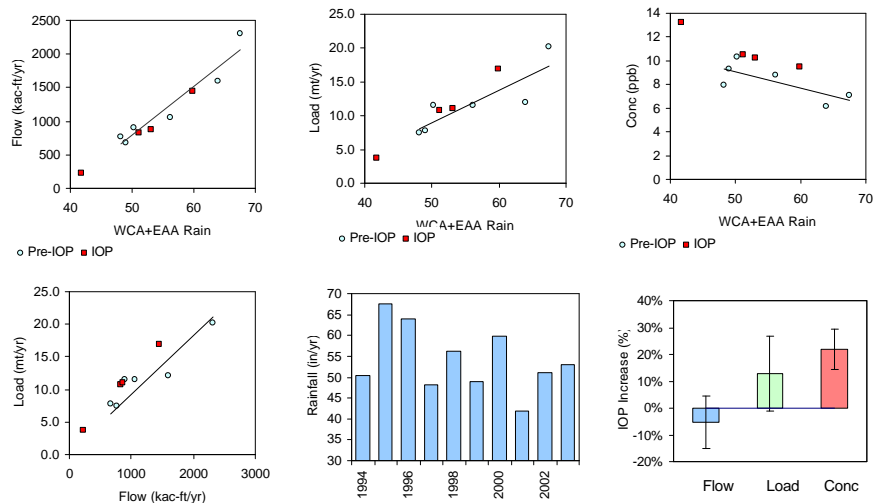
Observed Monthly Flows & Flow-Weighted Mean Concentrations
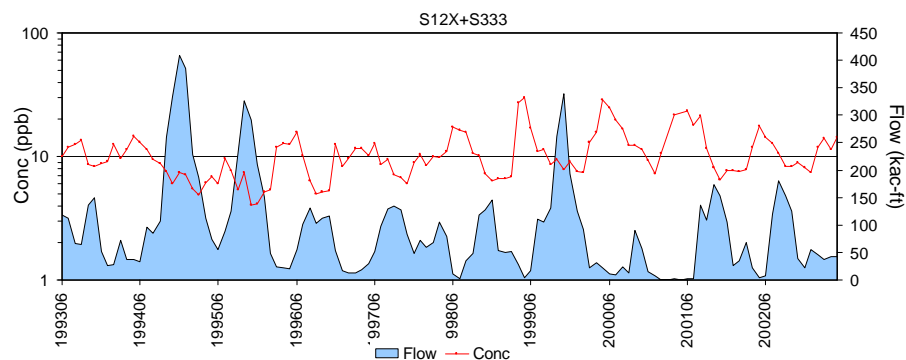
Water Year Time Series, Lines = Regressions vs. Rainfall for pre-IOP Period
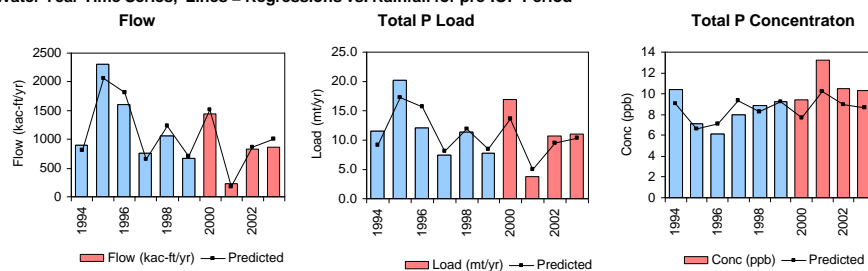
Pre-IOP Regressions:

June-May, 1994-2003					Rainfall Adjusted Values				Observed Values			
		Water Year			Flow	Load	Conc	FWConc	Flow	Load	Conc	FWConc
Period	Count	First	Last	Rain	kac-ft/yr	kg/yr	ppb	ppb	kac-ft/yr	kg/yr	ppb	ppb
All	10	1994	2003	54.1	1068	11285	9.3	8.6	1068	11285	9.3	8.6
Pre-IOP	6	1994	1999	55.9	1090	10736	8.6	8.0	1215	11722	8.3	7.8
IOP	4	2000	2003	51.5	1034	12107	10.4	9.5	847	10628	10.8	10.2
Increase				-4.4	-56	1371	1.9	1.5	-369	-1094	2.6	2.4
% Increase in Mean				-8%	-5%	13%	22%	19%	-35%	-9%	31%	30%
% Standard Error					10%	14%	7%					
Significance					0.31	0.20	0.01					
Regression R^2					0.94	0.82	0.82	Model : Y = B_0 + B_1 Rain + B_2 IOP, IOP = 0 or 1				

Figure 4. Analysis of Shark Slough inflow data.   Combined inflow = S12X + S333.   Example of analysis performed for each structure.

3.3 Screening Results

Screening results are summarized in Table 2. Percentage differences in flow, load, and concentration between the pre-IOP and IOP periods are shown in Figure 5 and mapped in Figures 6-8. Additional details (statistical modeling results, data plots, etc.) are given in the Appendix. Results are discussed by region (WCA-3A inflows, Shark Slough, Taylor Slough/Eastern Panhandle) below.

Table 2. Screening Analysis results. Pre-IOP = 1994-1999 mean,. Increase = IOP (2000-2003) mean – pre-IOP mean. % Incr = Increase as percent of pre-IOP mean. p = significance level, one-tailed test (* p < .15, ** p < .05). Values adjusted to average rainfall. Structures are defined in Table 1.

| Structure	Flow (kac-ft/yr) pre-IOP	Increase	% Incr	p		Total P Load (kg/yr) pre-IOP	Increase	% Incr	p		Mean Concentration (ppb) pre-IOP	Increase	% Incr	p	
WCA-3A Inflows															
S150	52	-11	-23%	0.48		3467	-588	-17%	0.63		56.6	-1.3	-2%	0.90	
S140	124	12	9%	0.50		6034	4730	78%	0.02	**	42.5	28.1	66%	0.06	*
G155	102	-50	-61%	0.03	**	22696	-9085	-40%	0.07	*	183.9	14.1	8%	0.77	
S190	80	11	13%	0.57		11647	217	2%	0.96		112.7	-3.6	-3%	0.86	
S8+G404	347	-23	-7%	0.69		39795	-1086	-3%	0.91		91.9	-3.5	-4%	0.83	
S11X	574	-130	-25%	0.12	*	18443	-5784	-31%	0.02	**	27.9	-6.0	-22%	0.21	
S9	235	32	13%	0.11	*	4091	2885	71%	0.01	**	14.3	7.4	52%	0.03	**
WCA-3A IN	1512	-160	-11%	0.20		106173	-8712	-8%	0.60		56.3	-0.3	-1%	0.97	
ENP Shark River Slough															
S12A	156	-11	-7%	0.78		1190	406	34%	0.24		7.0	2.8	40%	0.01	**
S12B	134	7	5%	0.81		1049	221	21%	0.47		6.6	1.1	17%	0.19	
S12C	281	-21	-8%	0.56		2467	-21	-1%	0.94		7.6	0.7	10%	0.35	
S12D	354	-50	-15%	0.25		3685	17	0%	0.98		9.0	1.8	20%	0.06	*
S12X	925	-76	-8%	0.54		8391	623	7%	0.63		7.9	1.5	19%	0.08	*
S333	166	20	11%	0.72		2345	748	32%	0.43		11.3	2.3	20%	0.02	**
S12X+S333	1090	-56	-5%	0.62		10736	1371	13%	0.39		8.6	1.9	22%	0.02	**
NESRS	157	-15	-10%	0.77		2127	392	18%	0.67		10.8	3.4	31%	0.01	**
SRS_ENP	1081	-91	-9%	0.46		10517	1015	10%	0.54		8.4	2.0	24%	0.02	**
ENP Taylor Slough/Eastern Panhandle															
L31N_IN	63	72	79%	0.01	**	1133	959	85%	0.05	*	13.1	-0.9	-7%	0.71	
S174+S332D	87	51	48%	0.04	**	1027	548	53%	0.31		9.1	-0.2	-2%	0.93	
S332+S175	203	-104	-64%	0.12	*	1858	-947	-51%	0.26		7.2	-0.6	-8%	0.68	
S176	89	-30	-39%	0.11	*	1125	-511	-45%	0.32		9.8	-1.7	-18%	0.58	
S177	131	4	3%	0.86		1140	513	45%	0.25		7.2	2.6	36%	0.20	
S18C	190	-10	-5%	0.69		2616	-691	-26%	0.46		10.5	-2.4	-23%	0.39	
S18C-S197	158	-6	-4%	0.84		1958	-447	-23%	0.60		9.4	-1.8	-20%	0.47	
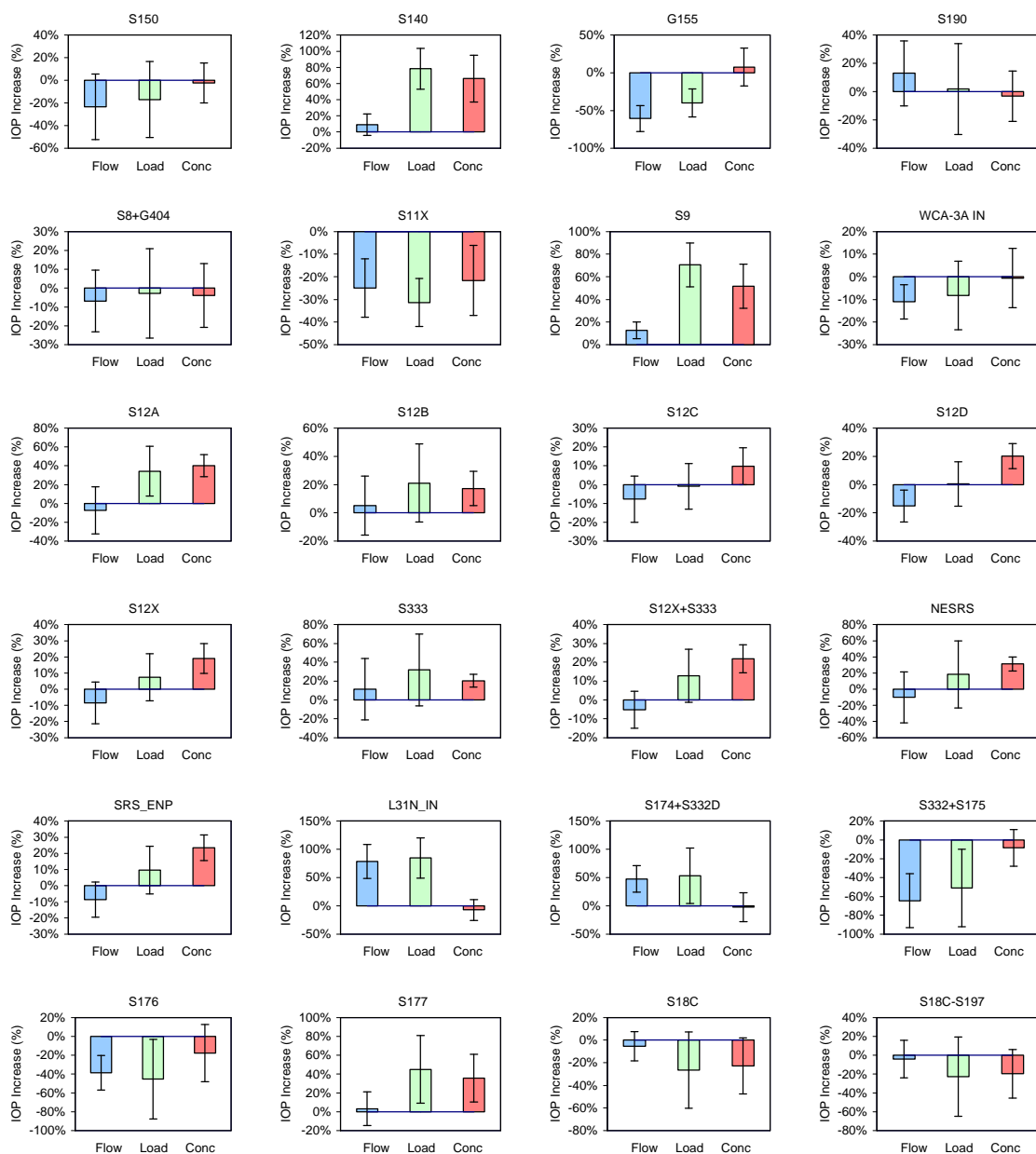
Figure 5. Changes in flow, TP load, and concentration. Increases (IOP mean – pre-IOP mean) as a percent of the pre-IOP mean.   Error bars are ± 1 standard error.
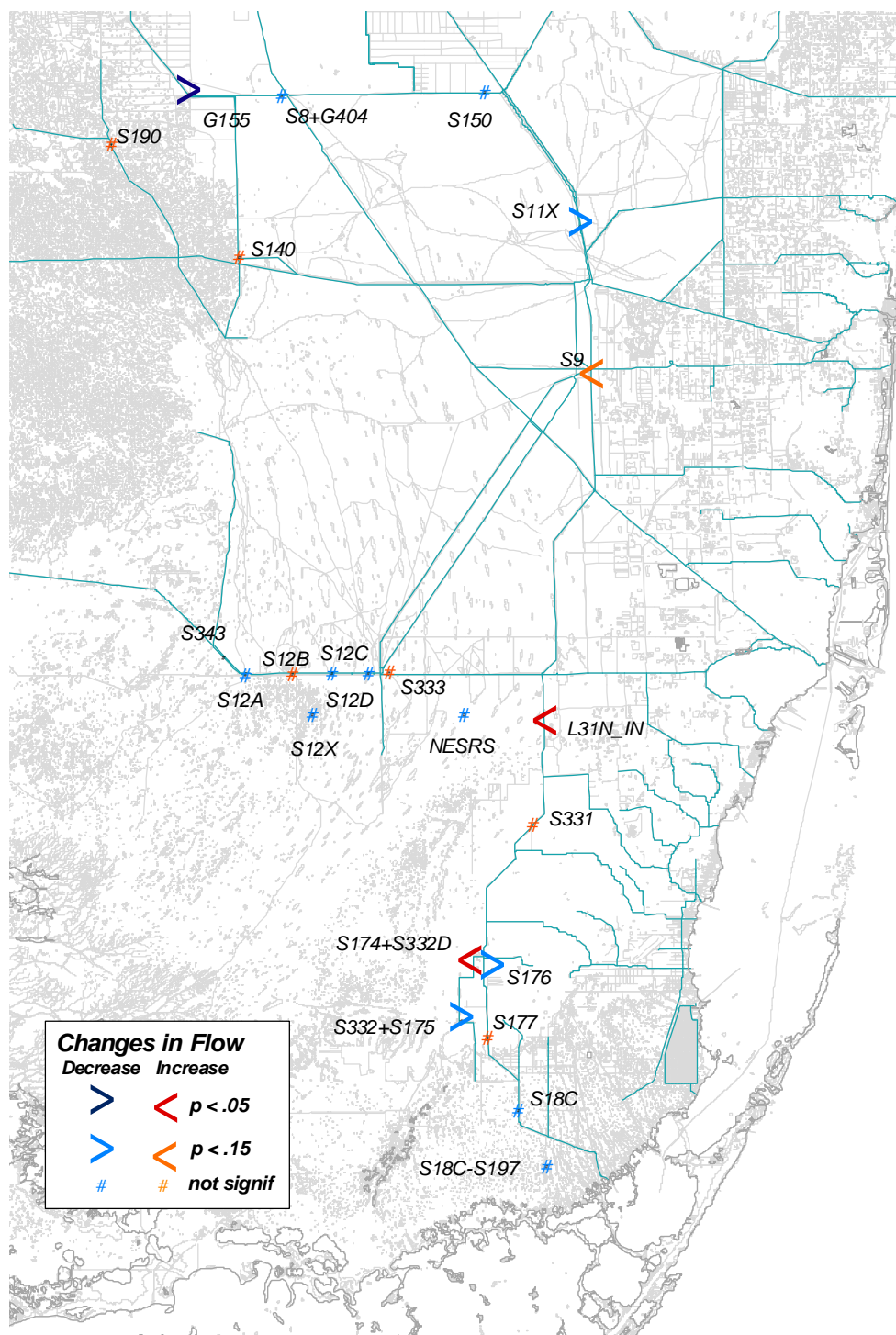
Figure 6. Map of changes in flow. Pre-IOP (1994-1999) vs. IOP (2000-2003) periods. Up arrow = significant increase (red p<0.05, orange p <0.15). Down arrow = significant decrease (dark blue p < .05, light blue p < 0.15).   Orange circle = increase, not statistically significant (p > 0.15). Blue circle = decrease, not significant (p > 0.15).   p/2 estimates the probability that the actual change was in the opposite direction from that indicated.
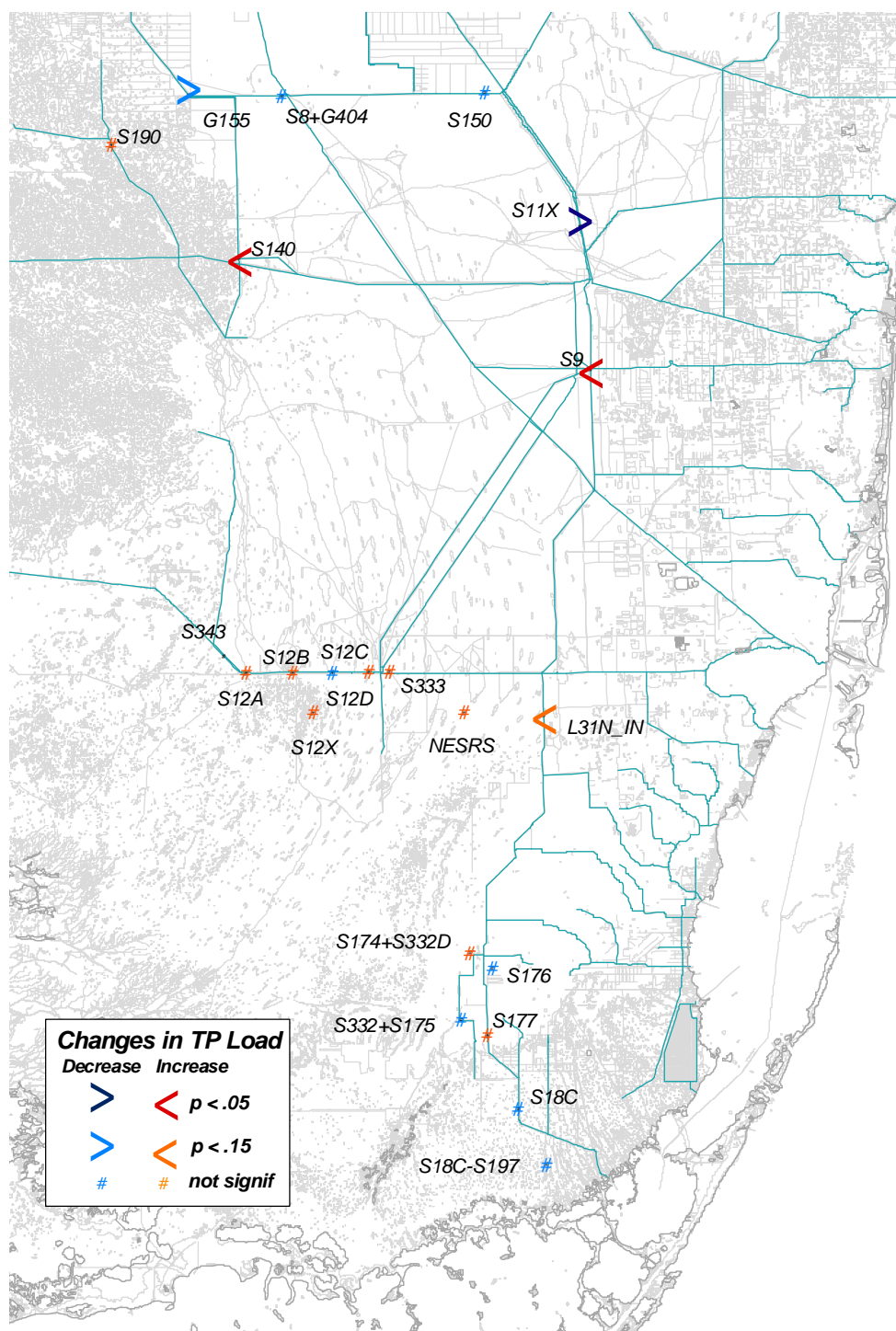
Figure 7. Map of changes in TP load. Pre-IOP (1994-1999) vs. IOP (2000-2003) periods. Up arrow = significant increase (red $p<0.05$, orange $p<0.15$). Down arrow = significant decrease (dark blue $p < .05$, light blue $p < 0.15$).   Orange circle = increase, not statistically significant ($p > 0.15$). Blue circle = decrease, not significant ($p > 0.15$). $p/2$ estimates the probability that the actual change was in the opposite direction from that indicated.
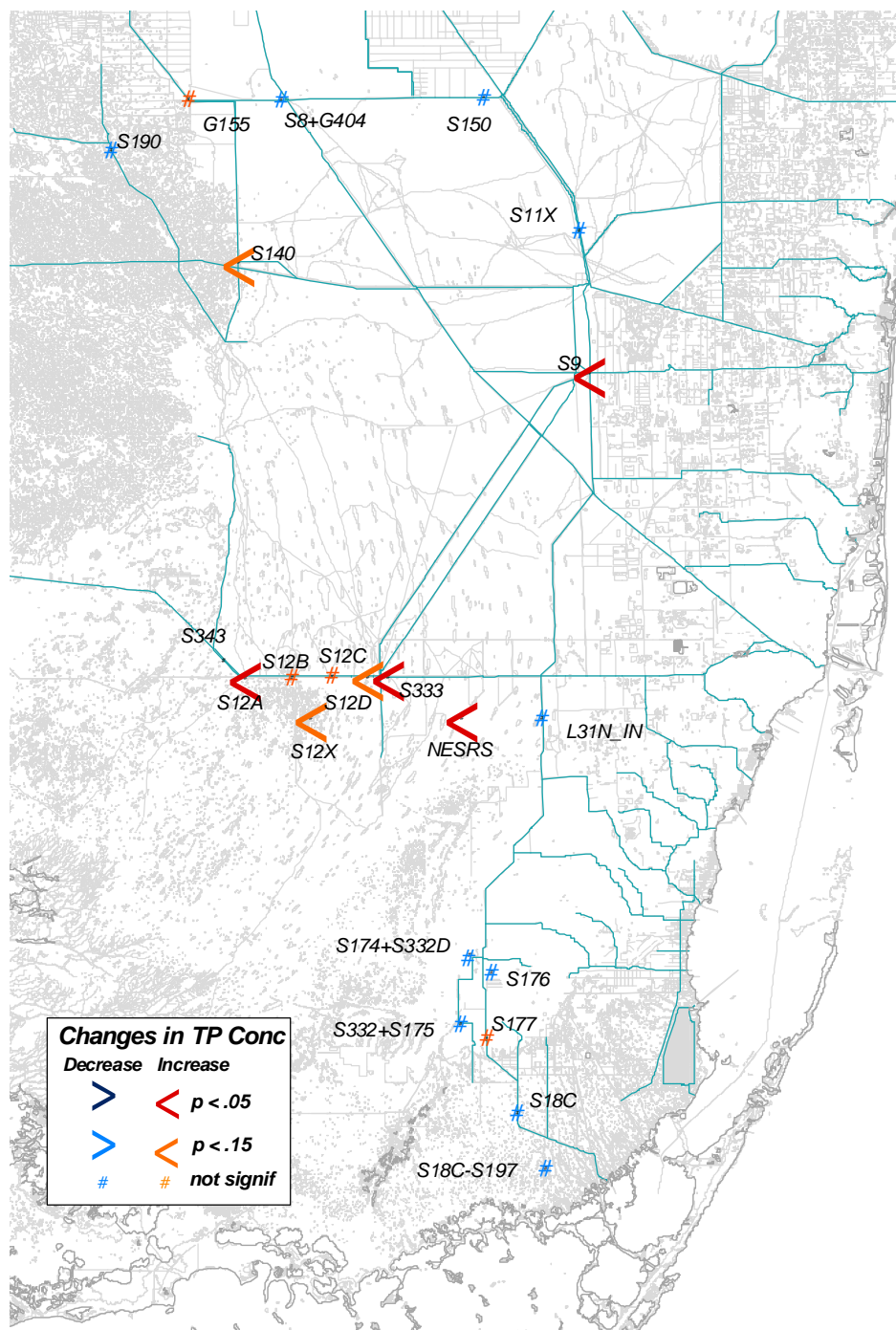
Figure 8. Map of changes in TP concentration. Pre-IOP (1994-1999) vs. IOP (2000-2003) periods. Up arrow = significant increase (red p<0.05, orange p <0.15). Down arrow = significant decrease (dark blue p < .05, light blue p < 0.15).   Orange circle = increase, not statistically significant (p > 0.15). Blue circle = decrease, not significant (p > 0.15).   p/2 estimates the probability that the actual change was in the opposite direction from that indicated. (Brandon changes in arrows)

3.3.1 WCA-3A

Apparent changes in WCA-3A inflows and potential causal factors include:

1. ***Decreases in G-155 flow and load.*** Flows discharged via G-155 into the northwest corner of WCA-3A originate primarily in the C-139 Basin. Recent reductions in flow and load can be attributed to diversion of most of the C139 basin runoff to Stormwater Treatment Area 5 (STA-5) in 2000. Discharges from STA-5 now enter the Rotenberger tract or the Miami Canal north of S-8. G-155 still receives STA-5 bypass flows and occasional diversions from the Miami Canal via G-404.

2. ***Decreases in S-11X flow, load, and concentration.*** S-11A, S-11B, & S-11C discharge from WCA-2A into northeast WCA-3A. The reduction in flow is possibly related to changes in water management, including reduction in regulatory releases from Lake Okeechobee to the Hillsboro Canal via S2, backpumping of EAA runoff to Lake Okeechobee to raise lake level during 2001 drought, and increased outflows from WCA-1 and WCA-2A to the east. The latter may be related to the IOP component that delivers additional flow from the WCA's to the L31N/C111 basin via canals on the eastern edge of the WCA's. Though not significant, the apparent decrease in concentration (22%, p = 0.21) may be related to reduction in phosphorus loads to WCA-2A when STA-2 started full-scale operation in July 2001 and/or reduction in lake releases to WCA-2A via S2/S7. Comparison of the pre- and post- STA-2 periods (1994-2000) vs. (2001-2003) indicates that there was a significant decrease in S-11X concentration (39%, p=0.02).

3. ***Increases in S-140 concentration and load***. Flows from the L-28 canal and the Western L-28 basin are pumped east into WCA-3A at S-140. Apparent increasing trends over the 1994-2003 period are not explained by rainfall or flow. It is unlikely that the trends were related to IOP. They may be related to changes in the drainage basin and/or diversions to the L-28 canal from inflows to the northwest corner of WCA-3A.

4. ***Increases S-9 in flow, concentration, and load.*** Runoff from the C-11 West basin is pumped into eastern WCA-3A at S-9. A portion of the flow is recycled seepage from adjacent WCA-3A and WCA-3B. Actual flow increases from this basin may have been higher because the data do not reflect flows from the smaller S9A pump station that was activated during the IOP period to handle seepage that was formerly handled by S-9. Apparent increasing trends in concentration and loads are not explained by rainfall or flow. It is possible that they are related to urban development in the C-11W basin.

5. ***Small decreases in the WCA-3A total inflow and outflow volumes.*** Increased inflows from S-9 were offset by decreases from S-11X and G-155. There were small apparent decreases in both total inflow (-11%, p=0.20) and outflow through

S-12X+S-333 (-5%, p=0.62), but these were not significantly different from zero.

6. ***No significant change in the total load or the average inflow concentration to WCA-3A.*** Increases in load at S-140 and S-9 were offset by decreases in load from G-155 and the S-11's.

7. ***Results indicate that diversions from the WCA's associated with the IOP may have resulted in small changes in the amount and distribution of inflow to WCA-3A***. Reductions in flow and load to the northern portion of WCA-3A can be attributed to STA operation. While apparently unrelated to the IOP, increases in load to the central portion of WCA-3A via S-140 (78%) and S-9 (71%) are of potential water quality concern because these inflows are closest to ENP inflow structures. The percentage of the total load to WCA-3A attributed to these sources increased from 9% in the pre-IOP years to 21% in the IOP years (Table 1).

3.3.2 Shark Slough

Apparent changes at ENP Shark Slough inflow structures include:

1. ***Increases in concentration.*** The combined flow-weighted mean concentration (S12X+S333) increased by 1.5 ppb or 19%. There was an apparent decrease in flow (-5%) and increase in load (13%), but these changes were not significant (p = 0.62 and 0.39, respectively). Concentration increased at individual structures by amounts ranging from 0.7 to 2.8 ppb, or 10 to 40%. The largest increase occurred at S12A and the smallest, at S12C.

2. ***Shift in WCA-3A outflows from the S-12X structures to S-333***. This shift is a consequence of the diversion of dry season flows away from western Shark Slough through S-333 to Northeast Shark Slough and the L-31N/C-111 basin. The overall pattern is consistent with the IOP strategy, although changes in yearly flows at individual structures were not statistically significant, partially because dry-season flows represent small portions of the total yearly flows.

Increases in phosphorus loads to the central portion of WCA-3A via S140 and S9 (WCA-3A inflow points closest to the Park inflow structures) may have contributed to the apparent increase in concentrations at the S-12's and S-333. The potential for phosphorus transport from these or other WCA-3A inflows to ENP inflow structures has not been evaluated. Such an evaluation would be complicated by mixtures of canal flow and marsh sheet flow through WCA-3A. Transport of loads from S-9 may be facilitated by the L67 levee along the southeastern border of WCA-3A, particularly when WCA-3A is at low stage and a higher fraction of the flow is likely to bypass the WCA-3A marsh.

The WCA-3A regulation schedule was modified under the IOP to allow drawdown of water levels by an additional 0.5 feet between February and mid July, as compared with the pre-IOP schedule (Figure 9). For the following reasons, it is likely that this change also contributed to the TP increases at ENP inflow structures:

An inverse relationship between TP concentration and water depth is typically observed at marsh monitoring sites in the Everglades, particularly at enriched sites. Stage dependence is reflected in marsh TP levels specified under the State/Federal Consent Decree for Loxahatchee National Wildlife Refuge (Hoeveler 1991; SFWMD 1993). The pattern is partially related to enhancement of P recycling from vegetation and soils at low water levels.

WCA-3A stage and the frequency of releases at low stage increased under the IOP. Daily stage and outflow (S12+S333) are plotted in Figure 10. Periods when flow was released at water levels below Zone E (pre-IOP) are indicated. While such releases occurred at various times throughout the 1994-2003 period, their frequency and magnitude (as a percentage of the total yearly outflow volume) increased after 1999.

Periods of WCA-3A drawdown were associated with spikes in outflow concentration and load discharged to Shark Slough. Monthly mean rainfall, stage, outflow, load, and concentration are shown in Figure 11. Outflow concentrations increased significantly when stage dropped below 9-10 feet. Both S-12X and S-333 concentrations were elevated during these periods. Spikes in outflow load occurred during periods of rising stage following drawdown, when rainfall and external phosphorus inputs to WCA-3A also increased with the onset of the wet season. The largest loading spike in the IOP period (~3500 kg/month) occurred in August 2001 after the lowest drawdown (~8.5 feet) in June 2001. Most of this load went into Northeast Shark Slough through S-333.

Monthly flow-weighted mean outflow concentrations are inversely correlated with stage. Correlations between outflow concentration and stage, outflow volume, and rainfall are shown in Figure 12. Lines show pre-IOP regressions. Stage explains a higher percentage of the variance ($r^2 = 0.57$), as compared with flow ($r^2=0.45$) or rainfall ($r^2=0.02$).

An inverse relationship between TP concentration and WCA-3A stage is evident at many structure and monitoring sites in WCA-3A and Shark Slough (Figures 13 & 14). Concentrations increase when stage drops below stage ~9.5 feet at all outflow sites (S-12X, S-333, US41-25), flows under the Tamiami Trail into Big Cypress (TAMBR105), interior sites in the central and southern portions of WCA-3A (CA311, CA315), and marsh sites in Shark Slough (P33, P35, P36, NP201, NE1). The pattern is less evident at sites in the northern portion of WCA-3A (CA32-38) possibly because these sites are located at higher elevations and are generally not sampled when the average WCA-3A stage is below 9.5 feet.
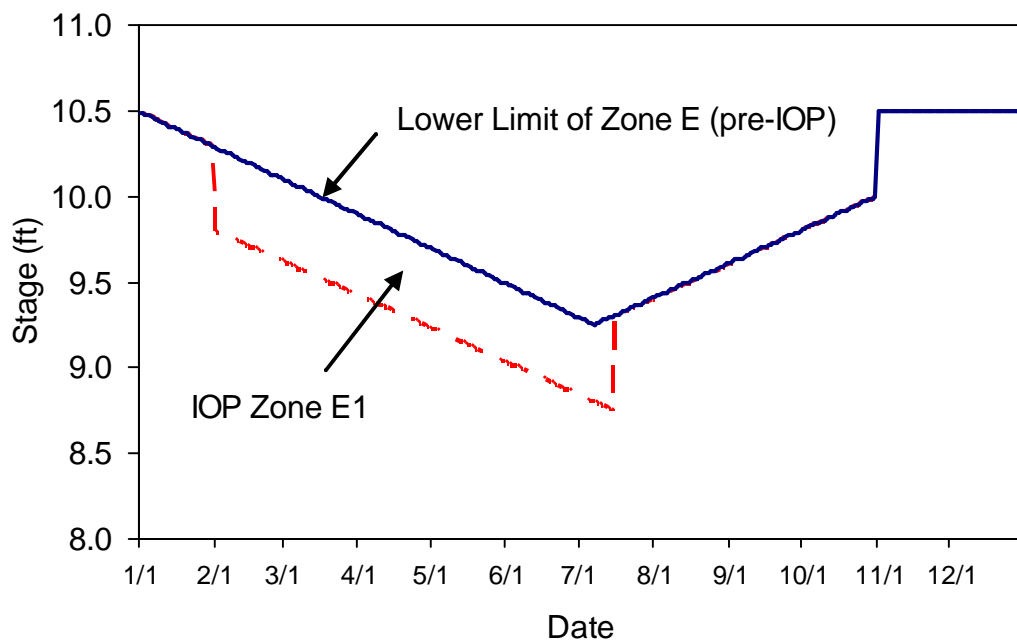
Figure 9. Change in WCA-3A regulation schedule. IOP Zone E1 allows a decrease of 0.5 feet in water levels between February and July, relative to the pre-IOP period.
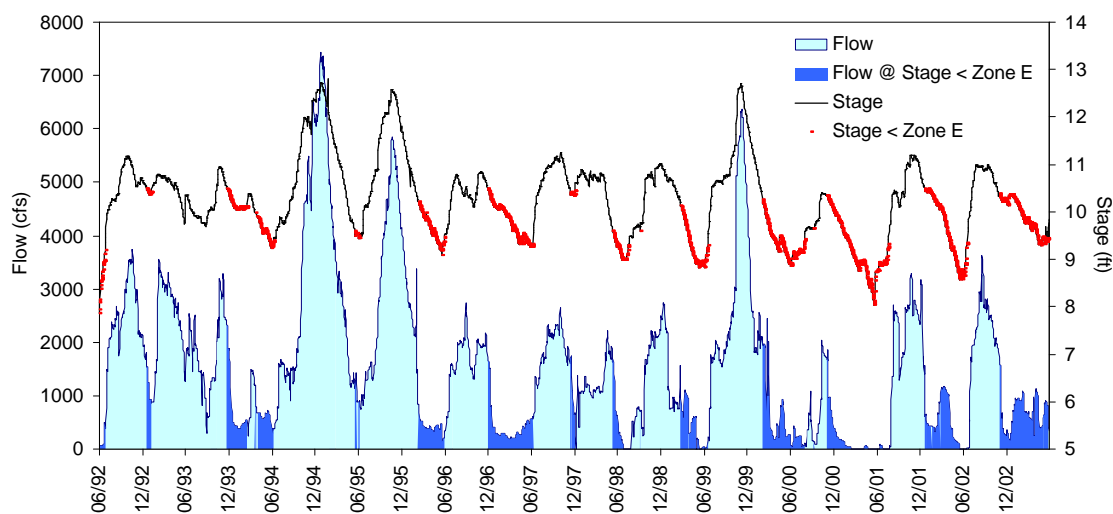

Figure 10. WCA-3A daily stage and outflow. Red line indicates days when stage was below Zone E of regulation schedule (in or below IOP Zone E1, as shown in Figure 9). Light & dark blue shaded areas are flows released above and below Zone E, respectively. Combined outflows through S12's and S333.
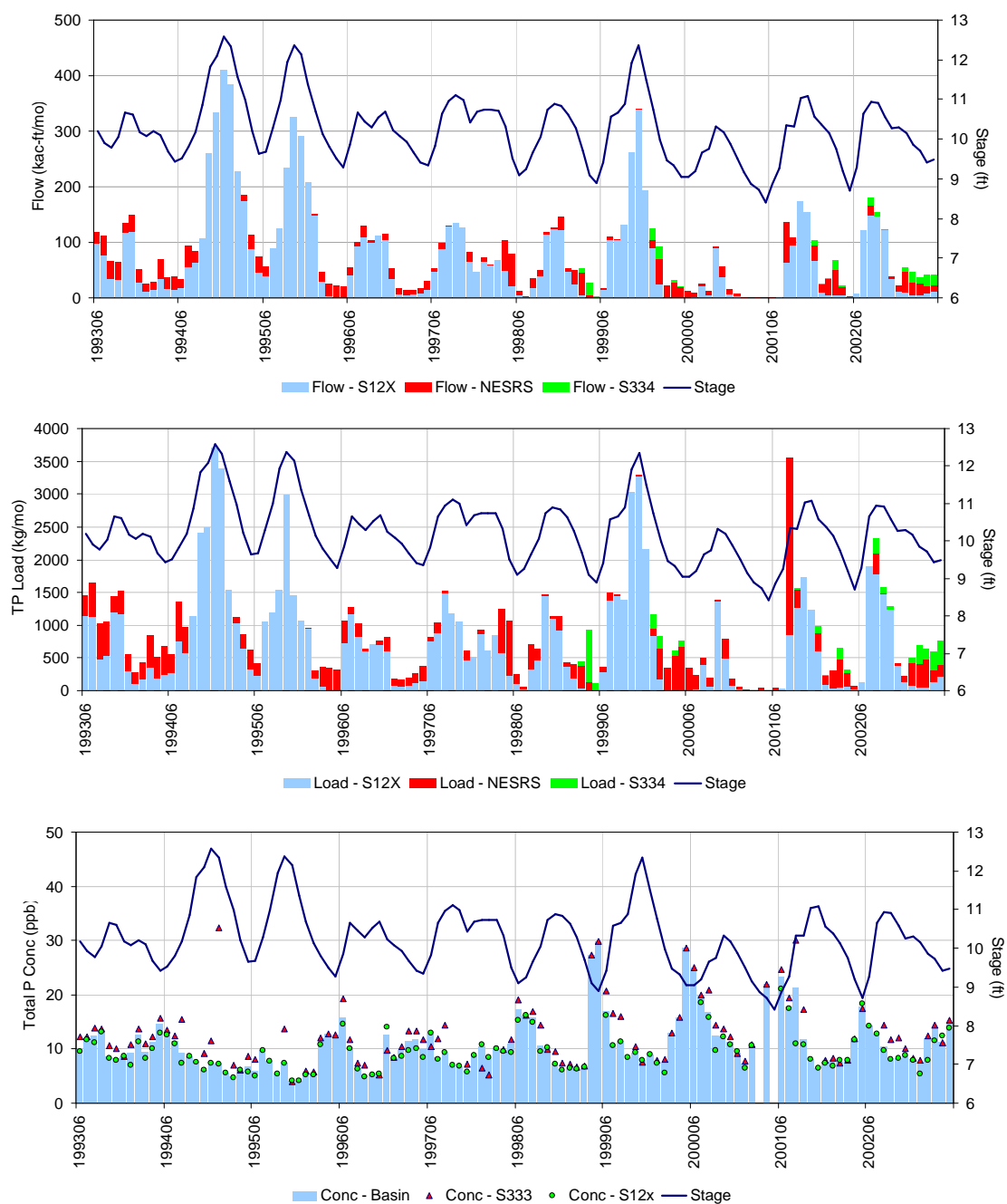
25

Figure 11. WCA-3A monthly stage and outflow. Combined outflows from WCA-3A through S12X, into NESRS through S333, or bypassed to L31N through S334. Bottom plot: triangles = S333 concentration; circles = S12x concentration; Bar = combined flow-weighted mean concentration; Line = WCA-3A stage.

26
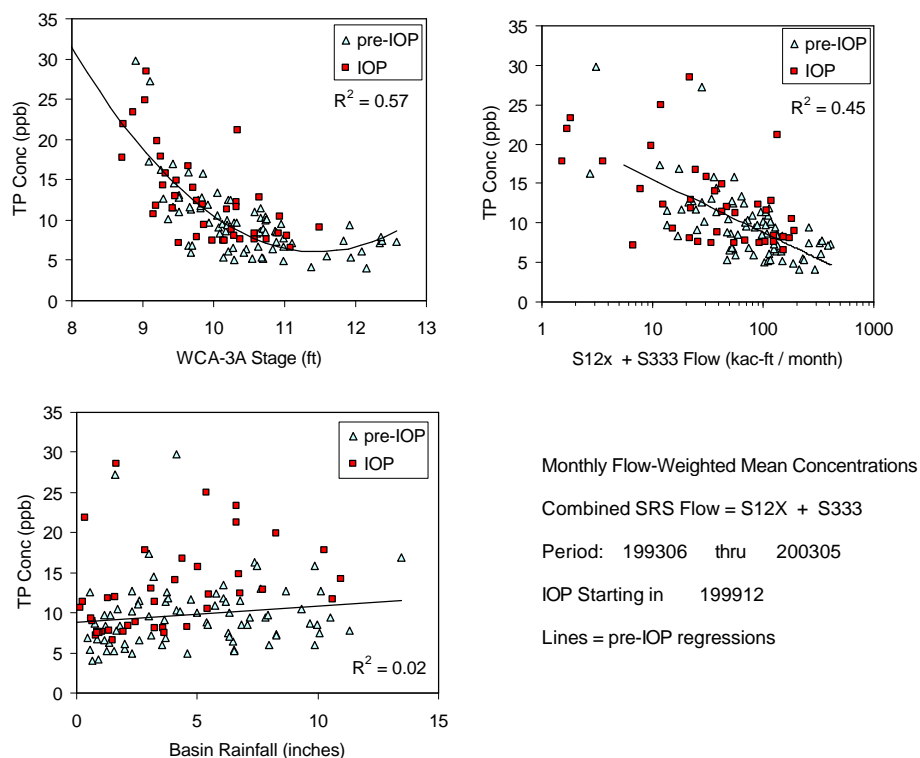
Figure 12.   Monthly TP concentrations in WCA-3A outflows vs. stage, flow, and rainfall. Combined outflows through S12X and S333. Triangles = pre-IOP period (June 1993 – November, 1999); Squares = IOP period (December 1999 – May 2003). Lines = pre-IOP regressions.

Figure 13. TP concentration time series at regional monitoring sites. Blue lines/ left axis = sample Total P (ppb); Red lines/right axis = WCA-3A stage (ft). Sites are sorted north to south and identified in Figure 1.

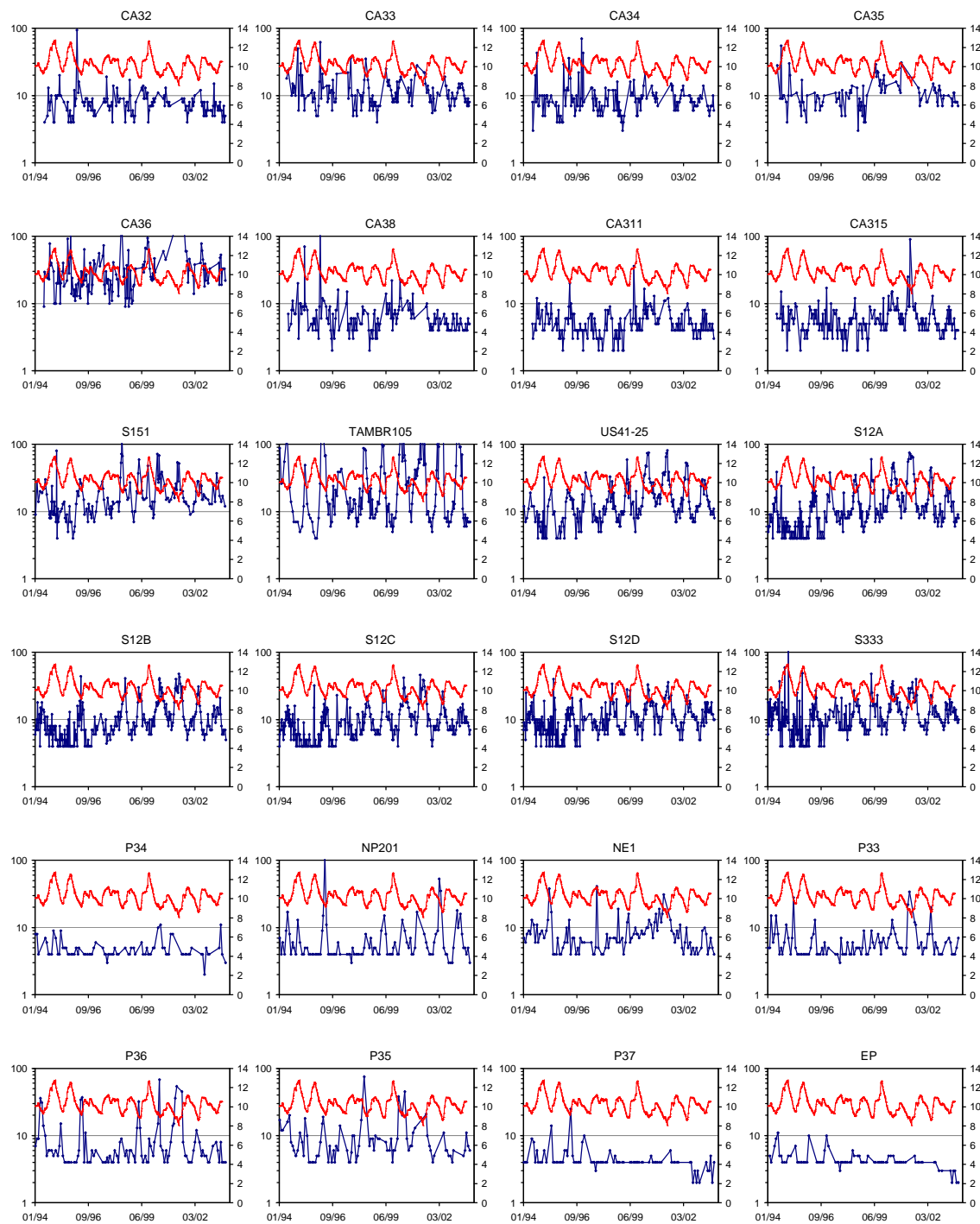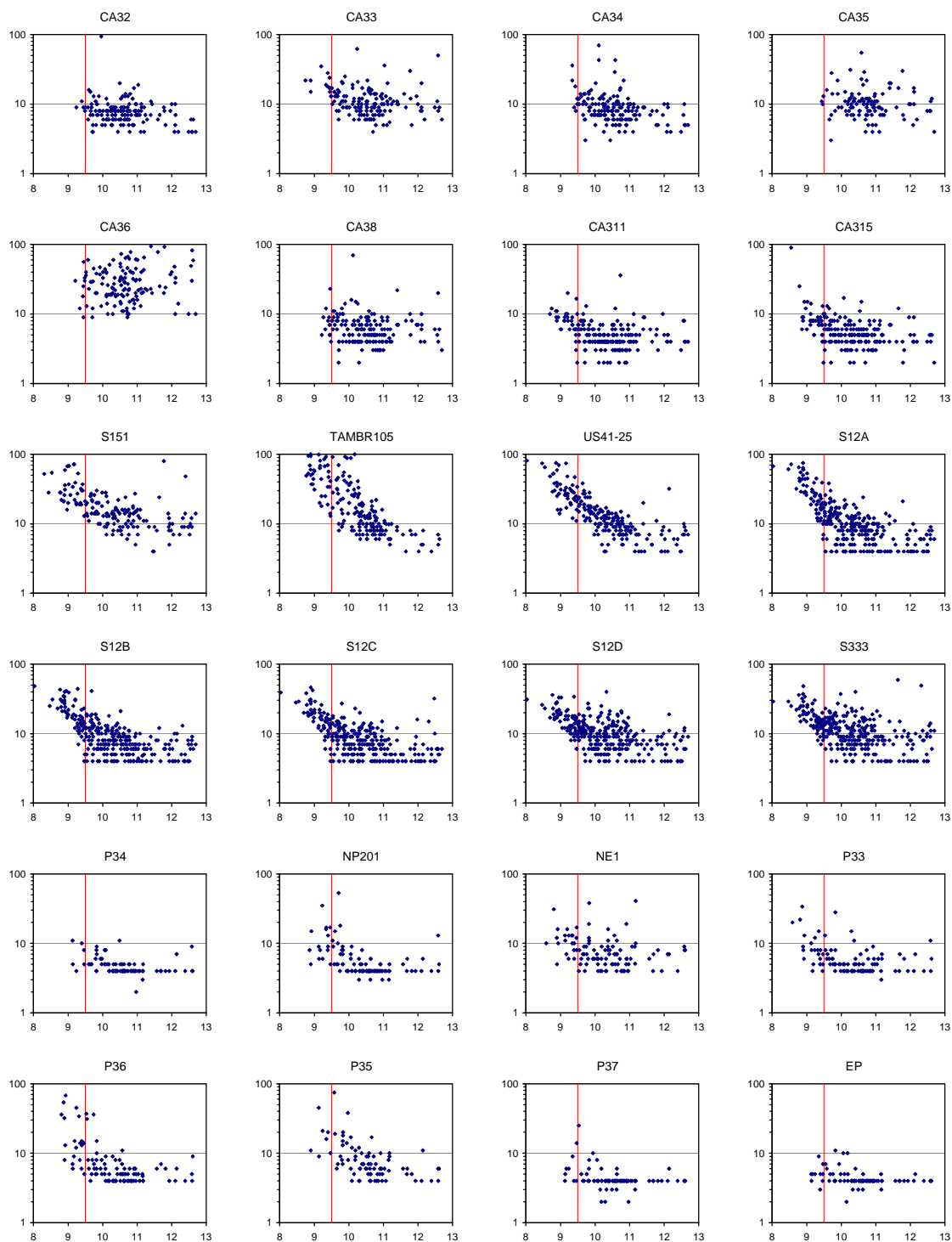Figure 14. TP concentration vs stage at regional monitoring sites.   Left Y-Axis = Sample Total P concentration (ppb); Right Y Axis = WCA-3A Stage (ft).

Low stages are to some extent unavoidable during drought. Figure 15 tests the
hypothesis that lower stages under IOP reflect variations in rainfall, as opposed to the
change in regulation schedule. Outflow characteristics (flow, load, concentration) and
various expressions of WCA-3A water levels are plotted against rainfall. Lines show
linear regressions for the pre-IOP years. The increase in average outflow concentration is
reflected by the fact that data from the IOP period consistently fall above the pre-IOP
regression. A similar pattern is observed for expressions of stage and drawdown (mean
stage, frequency below Zone E, percent of yearly flow released below Zone E, and
frequency of stage below 9.5 feet). These patterns suggest that lower stages observed
under IOP are not explained by variations in rainfall and are at least partially related to
the change in regulation schedule. Hydrologic analyses (Ahn 2003) indicate that
significant changes in dry-season stage occurred at several marsh sites in WCA-3A and
ENP SRS following implementation of IOP, allowing for variations in rainfall.

Increases in Shark Slough inflow TP concentrations under IOP are not entirely explained
by the change in regulation schedule, however. Outflow concentrations are plotted
against rainfall, stage, flow, and other measures of WCA-3A drawdown in Figure 16.
Lines show pre-IOP regressions. The IOP concentrations are consistently above the pre-
IOP regression lines in all cases except for that based upon the percentage of flow
released below Zone E.   While strongly correlated with the reduction in stage, shifts in
the distribution of flow away from the S-12's to S-333 is another operational change that
may have increased outflow concentrations by increasing the ratio of WCA-3A marsh
sheet flow to canal flow in the combined outflows. This factor is somewhat discounted,
however, because (1) the concentration increase was greater at S-12A than at the other
structures (40% vs. 10-20%, Table 2), (2) the amount of flow shifted was a small fraction
of the annual flow volume; and (3), the fraction of yearly flow volume discharged
through S333 was not significantly higher in the IOP years as compared with the pre-IOP
years at a given rainfall (Figure 15). Further analyses, including monthly time series
modeling, indicate that the concentration increases are not entirely explained by WCA-
3A drawdown. Outflow concentrations also tend to exceed pre-IOP regressions in
months with high stage (>10.5 ft) or rainfall (> 3 inches/month) (Figure 12).
Concentrations during these periods have a large impact on the yearly flow-weighted
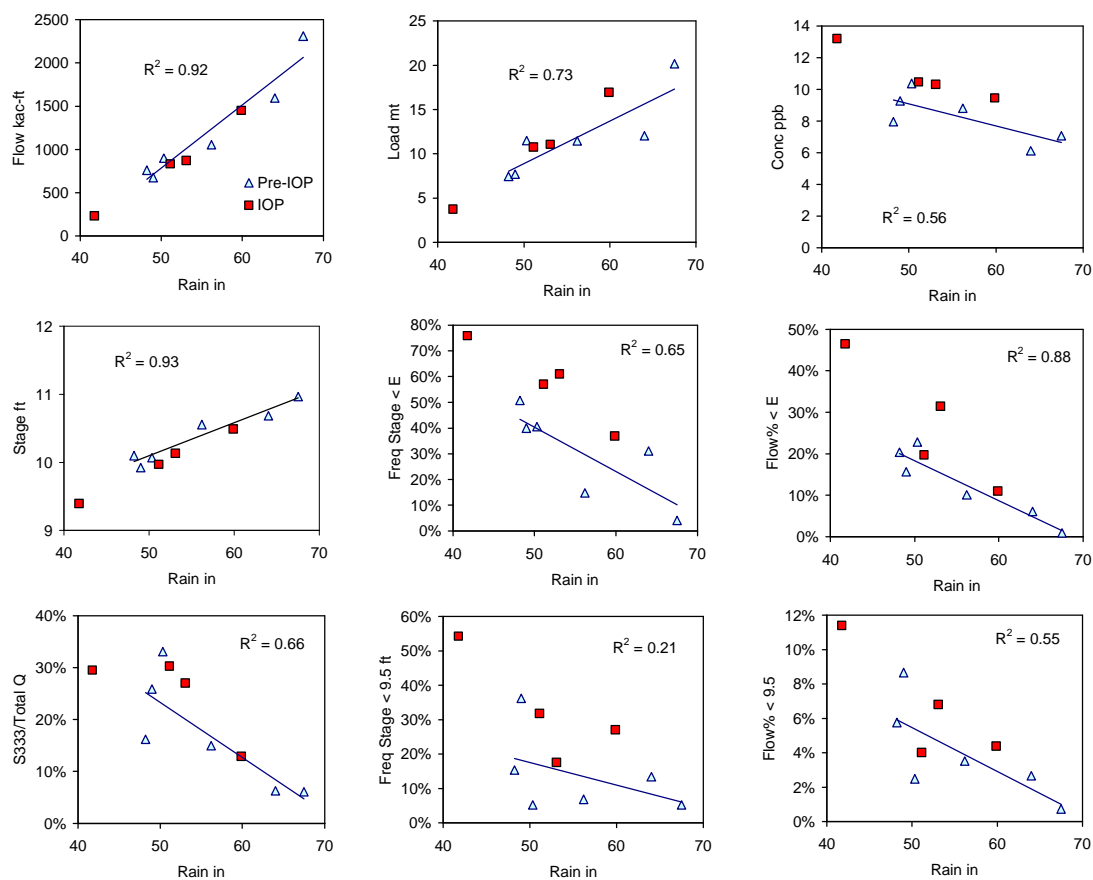means.

Figure 15. P and related hydrologic variables vs. basin rainfall.   Combined WCA-3A outflow through S-12's & S-333. Triangles = pre-IOP years (1993-1999). Squares = ISOP/IOP years (2000-2003).   Lines = pre-IOP regressions. Hydrologic variables are defined in Figure 16.
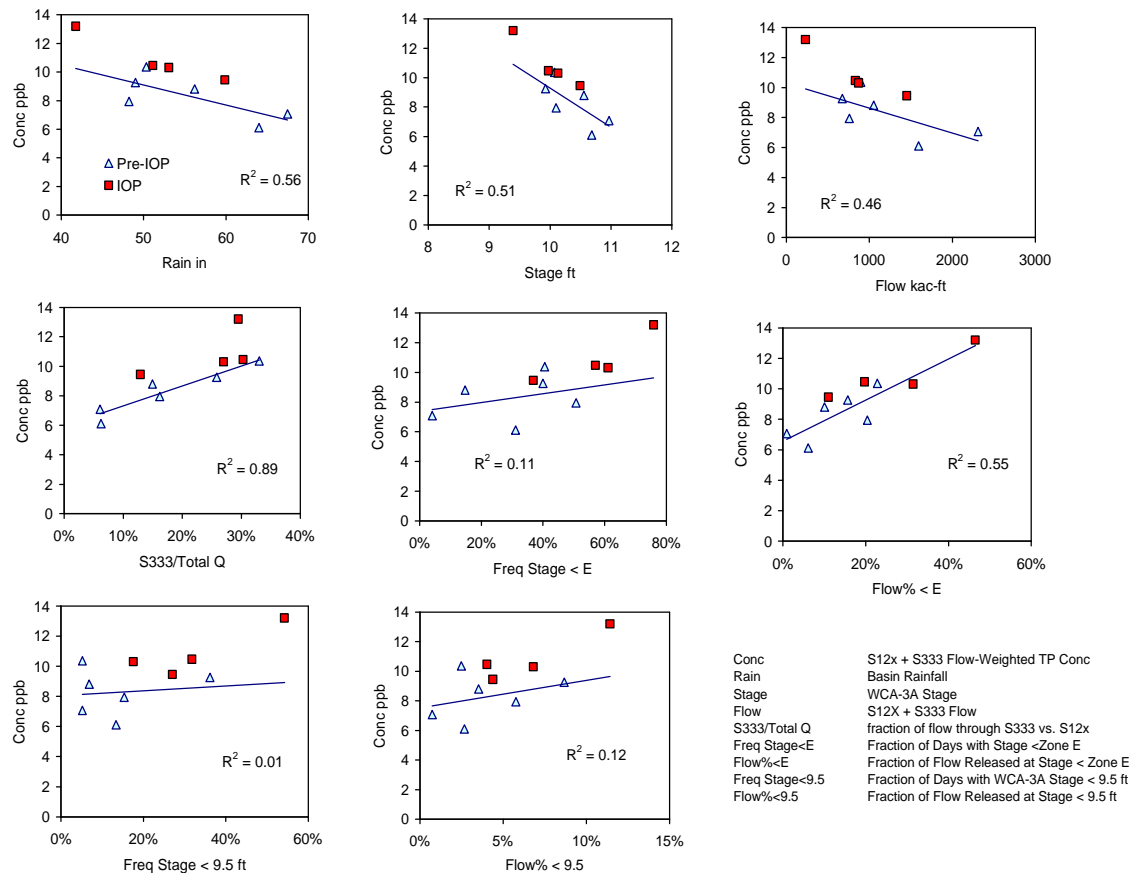
Figure 16. WCA-3A outflow P concentration vs. basin rainfall and related hydrologic variables. Combined outflow through S12's & S333. Triangles = pre-IOP years (1993-1999). Squares = ISOP/IOP years (2000-2003). Lines = pre-IOP regressions.

No significant changes in average Shark Slough inflow concentrations after IOP implementation were found when the above analysis was repeated using a 1988-1999 (vs. 1994-1999) baseline period. While the longer baseline is desirable because it includes dry years (Figure 2), interpretation of the results with respect to IOP impacts is difficult because the variety of operational schemes utilized during this extended period and possible shifts in the baseline attributed BMP implementation in the EAA during the mid 1990's.

In summary, potential mechanisms responsible for the observed ~20% increase in WCA-3A outflow concentrations to Shark Slough between 1994-1999 and 2000-2003 include:

1. Increases in external TP loads to the central portion of WCA-3A via S-9 and S-140;
2. Increases in TP recycling from marsh soils and vegetation promoted by WCA-3A drawdown under the IOP;
3. Increase in the proportion of flow through S-333 vs. S-12X.

4. Enhancement of phosphorus transport from external sources through WCA-3A as a consequence of drawdown and its associated hydraulic effects:
   a. Decreases in WCA-3A area, storage volume, and water residence time required for assimilation of external loads by the WCA-3A marsh;
   b. Increases in the proportion of canal flow vs. marsh sheet flow at low stage, particularly down the Miami Canal and along L67.

The relative importance of these mechanisms is not understood. The fourth mechanism suggests a possible interaction between the apparent effect of IOP (WCA-3A drawdown) and transport of external loads through WCA3A. Development of an understanding of these mechanisms and interactions is recommended to support future management of the system to attain hydrologic and water quality goals.

3.3.3 Taylor Slough/Eastern Panhandle

Apparent differences between the 1994-1999 and 2000-2003 periods in ENP's Taylor Slough and Eastern Panhandle basins include:

1. ***Increase in flow delivered to the L31N canal from the North (S-334 + S-335 – S-336).*** This is consistent with the IOP strategy to divert flows away from western Shark Slough and the WCA's to the L-31N/C-111 basins. Concentrations were not measured at S-335, so that impacts on load and concentration entering the L-31N are based upon concentration measurements at S-333.

2. ***No change in G211 or S331 flow.***   Most of the increased flow delivered to L-31N through S-334 and S-335 was diverted east through S-338 (Figure 3). This indicates that there was no net increase in flow delivered to the southern L-31N/C-111 canals from the WCA's under IOP. P data are insufficient to test for changes in load or concentration at G-211 or S-331, so results are not reported along with those for other structures.

3. ***Increase in S-174+S-332D flow***. These are discharges from L-31N west to L-31W and the S-332D detention/Frog Pond area. The increase reflects operation of the S-332D pump station starting in 1999. The S-332B and S-332C pump stations also diverted additional flows to detention areas west of L-31N (not shown because of there was no baseline).   These do not necessarily represent increases in flow delivered to ENP because of seepage return from the detention areas to the L-31N/C-111 canals.

4. ***Decrease in S-332+S-175 flow***.   These direct discharges to Taylor Slough from the L-31W were essentially stopped in 2000 under the plan to modify deliveries to the Slough.

5. ***Decrease in S176 flow.*** This is consistent with diversions from L31N to the west via S332D and S332B.

6. ***No change in S-177 flow.*** The flow deficit at S-176 did not occur farther downstream at S-177. This may be attributed to seepage return from the S-332D detention area and/or increased groundwater inflows from the east attributed to operation of lower L3-1N canal levels under IOP.

7. ***No change in S-18C flow or net delivery to the ENP Eastern Panhandle (S-18C- S-197).***   Despite increased pumping out of the L-31N into the buffer zone via S-332D and S-332B, there was no net decrease in flow at S-18C. This suggests that most of the flow pumped west into the detention areas seeped back into the L-31N/C-111 canals above S-18C. Increased seepage inflows from the east and west as a consequence of lower canal operating stages under IOP may have also offset the flows pumped out of the L-31N into the detention areas.

Screening of the L-31N/C-111 data identified no significant changes in phosphorus concentration after IOP implementation. Any changes that may have occurred over the 1994-2003 period could not be detected in the presence of background variability in the data. There are some signs of improvement in the basin, but these cannot be confirmed statistically or ascribed specifically to IOP. With the exception of S-177, there were apparent decreases in concentrations after IOP, but these changes (2% to 23%) were not statistically significant. There were also apparent declining trends at ENP marsh sites P37 and EP over the 1994-2003 period (Figure 13), but confirmation of these trends is difficult because of the low concentration range and decrease in P detection limit from 4 to 2 ppb in 2002, which may affect comparability with data from previous years. Independent analyses of SFWMD data by the U.S. Army Corps of Engineers (2003) identified decreasing trends at S-176 and S-18C between 1983 and 2002. Given the length of the period and data limitations discussed below, however, these apparent trends cannot be ascribed specifically to the IOP.

The following factors and data limitations, most of which are less important in or absent from the Shark Slough data, contribute to variability in the data from this basin and reduce probabilities of detecting changes. The recent data may not adequately reflect long-term water quality conditions likely to result from continuation of the IOP, particularly with future evolution of the C-111 project and potential urban development in the region. Factors include:

1. There is greater year-to-year variation in flow-weighted-mean concentration at L-31N/C-111 structures (CV = 0.25 – 0.45), as compared with Shark Slough structures (CV = 0.15 – 0.25). This is partially attributed to lower analytical precision in the lower concentration range. Greater variation decreases the probability of detecting change in a dataset of fixed length (Snedecor & Cochran 1989).

2. Adjustments for rainfall generally removed less variance from data at sites in this basin, as compared with sites in Shark Slough and WCA-3A. This may reflect the fact that hydrologic variability in the system is controlled more by seepage, canal

stages, and local inflows, as opposed to WCA rainfall. Screening results did not change significantly using rainfall measured at S-18C instead of the WCA/EAA basin average.

3. The 2000-2003 IOP period did not include wet years, which would be critical to evaluating long-term water quality impacts of operating the system (via the S-332B/C/D pumps and lower canal elevations) to provide flood control for areas east of the canals.

4. Similarly, wet year data are needed to assess critical conditions and long-term-average loads at S-18C, which are influenced by direct agricultural runoff via the C-111E canal via S-178.   While flow data are insufficient to evaluate loading at S-178, geometric mean concentrations at this site increased from 21 ppb in the 1994-1999 to 32 ppb in 2000-2003. Unlike most other sites in the ENP region, concentrations at S-18C tend to increase at high flows, a pattern typical of sites influenced by runoff (e.g., S-9 or S-8). For example, monthly flow-weighted concentrations at the S-12's generally decrease from ~15 ppb at low flows to ~6 ppb at high flows, whereas concentrations at S18C increase from ~6 ppb at low flows to ~20 ppb at high flows. Canal water budgets indicate that under the dry-average rainfall conditions typical of 2000-2003, flow and concentrations at S-18C are likely to be dominated by seepage from ENP and the L-31N/C-111 buffer cells, as opposed to watershed runoff.

5. With the exception of S-332D, the screening analysis is based exclusively upon biweekly grab samples. This sampling strategy is generally inadequate for detecting infrequent spikes in concentration and loading associated with runoff events and flood-control operations. Such spikes may account for a large fraction of the total annual load at a given site. Grab sampling may be adequate to measure loads at the S-12's, but continuous flow-weighted composite sampling is needed to measure loads at S-18C and other sites in the basin possibly affected by runoff events or flood control operations. Figure 17 compares SFWMD grab and weekly composite samples at S-332D and S-18C. Composites are significantly higher than grabs in some periods, particularly when flows are high. Because S-18C composite sampling was not initiated until 2003, the above screening analysis was based exclusively upon grab samples at that location. While it is possible that some of the differences between grabs and composites can be attributed to initial "shake-down" of the automatic sampling devices or other artifacts, there is a significant risk that grab samples under-estimate flow-weighted-mean concentrations and loads at these and other structures in the basin.

6. The initial phases of the C-111 buffer project (including S-332B, S-332C, S-332D, and their associated detention areas, and other components) were not in full scale operation in the 2000-2003 IOP period analyzed. Local inputs to the L-31N/C-111 canals are diluted by seepage losses from the Park (Walker 1997). An increase in concentration would be expected when the buffer project is in full operation and seepage losses are reduced, particularly if the system is operated to

provide additional flood control for developed areas east of the canals. Occasional phosphorus spikes (20 – 90 ppb vs. baseline < 10 ppb) in the C102 and C103 data from 2001-2003 (Anamar Inc. et al. 2003) provide evidence of inputs from eastern developed areas that are inadequately characterized by grab sampling. Contributions from these areas will increase with future land use changes and/or system operation to provide additional flood protection (Harper 1994).
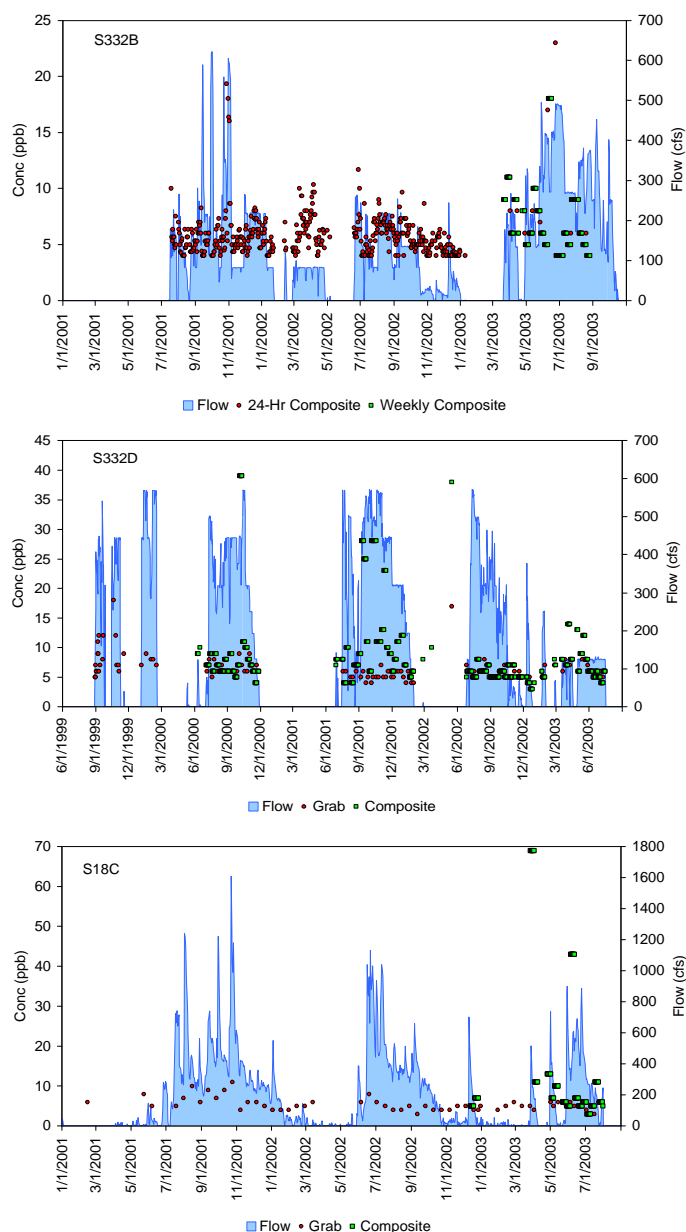

Figure 17. Comparison of Grab and Composite Samples at S-332B, S-332D, and S-18C. Total phosphorus concentrations (ppb). Green Squares = weekly composite samples. Red Circles = grab samples (24-hr composites for S-332B). Blue area = daily flow (cfs). Data are from SFWMD (S-18C, S-332D) and the U.S. Army Corps of Engineers (S-332B).

Historical data do not provide evidence of water quality deterioration in the L-31N/C-111 basin as a consequence of IOP and other changes in system operation that occurred in the 2000-2003 period. Given data limitations and difficulties associated with forecasting effects of C-111 project completion, changes in operation, and changes in land use, future management should be guided by intensive monitoring, data analysis, modeling, and research to develop a better understanding of mechanisms controlling hydrology and water quality.

3.3.4 C-111 Detention Areas

The U.S. Army Corps of Engineers (USACOE) has proposed, designed and partially constructed a set of detention basins along the eastern edge of ENP, for the purposes of flood protection for areas to the east of the C-111 canal. These basins are also intended to conserve high quality water in ENP, by preventing subsurface flow from the Park to the east. From north to south, these basins are S-332B, S-332C and S-332D.

These basins are intended to have partial and episodic overflows into ENP. As a consequence, the quality of those overflows must be of acceptable quality, especially with regard to P content. This requirement led to the initiation of a water quality demonstration and research project, sited to the south of pump station S-332D, in the area known as the Frog Pond. The intent of the project was to demonstrate that a periphyton/submerged aquatic vegetation system could provide the requisite water quality, and to seek optimal designs and operation strategies for the basins.

Plans for this field-scale water quality demonstration project have progressed through several iterations, starting with a draft proposal put forth in 1996, in an undated draft document entitled "Periphyton Stormwater Treatment Area Test Project" produced by the USACOE. Subsequent draft designs have been put forth in every year except 1999.

These conceptual, preliminary plans involve using a portion of the Frog Pond as a detention zone for water pumped at S-332D. The objective would be to treat the water while it is in the detention zone so that, by the time the water reaches ENP via Taylor Slough, it would meet water quality standards.

As of the year 2000, the USACOE believed that an appropriate technology could be quickly found and quickly implemented: "As construction of the May 1994 GRR plan continues more knowledge of the water quality conditions created by the plan will be learned. It is likely that water quality treatment technologies will be developed and refined during this construction period. With this information, the appropriate details of the conceptual, preliminary plan for using the Frog Pond as a water quality treatment area could be finalized. The process of implementing a water quality treatment plan in the Frog Pond would likely be of short duration because the Frog Pond is available for project purposes and there is a preliminary, conceptual plan that does exist for its utilization as a site for water quality treatment." (USACOE 2000a). Unfortunately, no such quick solutions have been found, researched or implemented.

4. Field Scale Demonstration: Basis of Design

Constructed and natural periphyton-dominated wetlands may be capable of absorbing new phosphorus loadings, and in appropriate circumstances may provide a low cost alternative to chemical and biological treatment. P interacts strongly with wetland soils and biota, which provide both short term and sustainable long term storage of this nutrient. Soil sorption may provide initial removal, but this partly reversible storage eventually becomes saturated. For limerock soil conditions, P sorption is not expected to contribute significantly to temporary short-term removal. Uptake by small organisms, including bacteria and algae, forms a rapid action, mostly reversible removal mechanism. Cycling through growth, death and decomposition returns most of the microbiotic uptake via leaching, but an important residual contributes to long-term accretion in newly formed sediments and soils. Submerged and emergent macrophytes, such as *Eleocharis*, *Panicum, Nymphaea*, and *Utricularia*, follow a similar cycle, but on a slower time scale of months or years. The detrital residual from the macrophyte cycle also contributes to the long term storage in accreted solids.

Non-emergent wetland systems (NEWS), which include mixtures of submerged aquatic vegetation (SAV) and periphyton in varying proportions, are the only known ecosystems that presently hold out hope for attaining the 10 ppb TP concentration believed necessary to protect Everglades resources. It is appropriate to consider and explore both extremes of the NEWS concept, periphyton and SAV.

Constructed systems dominated by SAV have been successful in closely approaching the 10 ppb goal in small units, and are being studied at all scales from mesocosms up to 2000 acre cells in the stormwater treatment areas (STAs). There is a possibility that SAV wetlands can be improved to produce 10 ppb water.

Natural Everglades periphyton-dominated wetlands exist and function at phosphorus levels below 10 ppb. Constructed wetlands dominated by periphyton, termed periphyton stormwater treatment areas (PSTAs), have also been successful in closely approaching the 10 ppb goal in small units. There is a possibility that PSTA wetlands can produce 10 ppb water. Extensive research at sizes up to five acres has been conducted over the past five years. While some PSTA questions remain that could be addressed in small units, the preponderance of remaining issues can only be addressed in larger systems.

In January 1996, Doren and Jones coined the acronym PSTA (Periphyton Stormwater Treatment Area). Doren and Jones (1996) observed that soil and vegetation had been successfully removed, down to bedrock, in the Hole-in-the-Donut (HID) project in ENP. They also observed that natural periphyton communities of the southern Everglades exist at low phosphorus concentrations (ca. 10 ppb or less). They then concluded that the HID methodology could be directly applied as a methodology for achieving required water quality in the C-111 project areas. This early concept was implemented in the construction of the S-332B, S-332C and S-332D detention areas. These detention areas were scraped down to bedrock, and provided with overflow spillways and gated discharge structures (S-332D). These detention areas were constructed during the course of activities concerning the design of a water quality field scale demonstration project, in the year 2002 as in the case of the S-332D basins in the Frog Pond. Early design

opportunities and constraints were significantly altered, and as a result, re-design of the field scale research and demonstration project was initiated in January 2003.

5. The S-332D Site and Background Monitoring

The S-332D detention area consists of four sections (Figure 1(18)): (1) a high-head cell that receives water from pump station S-332D, which then spills over a broad concrete weir into (2) a rectangular scraped-down cell of approximately 400 acres, which then spills over a broad earthen weir into (3) an L-shaped scraped-down cell of approximately 400 acres, which then spills over a broad concrete weir into (4) a flow-way, scraped-down for its first third and vegetated for the last two thirds, which then spills over a degraded levee into the L31W canal.

The selected site for the USACOE water quality field scale project is the northern-most 400-acre cell (Cell 4 of the entire C111 detention works) of the S-332D detention area (Figure 18). All recent iterations on water quality pilot project layouts place research cells in the northeastern portion of Cell 4, adjacent to the high head cell. This very flat, former agricultural area has been scraped down to bedrock, with the exception of remnant natural wetland areas. Scrape down and leveeing activities were completed, and water introductions started, in June 2002. Because of this intended siting of the water quality project in the S-332D detention area, a program of groundwater and surface water monitoring was established in the new S-332D detention area cells and adjacent areas.
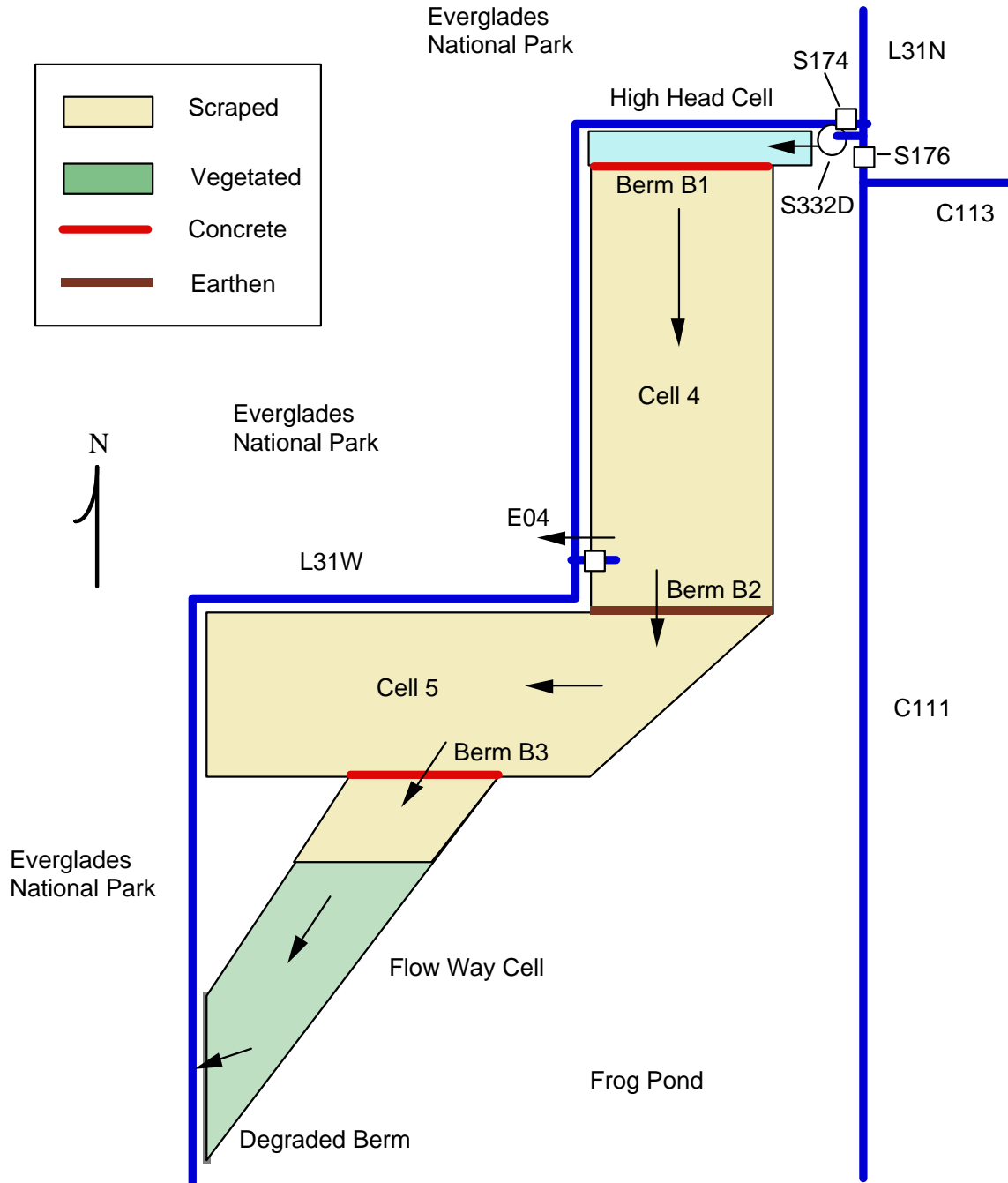
Figure 1 18: General Layout of S-332D, canals, pump stations. (Not to scale)

Groundwater monitoring wells were established at eleven locations on two east-west transects, at 20 and 40 foot depths (Figure 19). Additional two-well clusters were located to the northwest (ENP) and southeast (Frog Pond) of Cell 4 (Figure 19). Surface water quality monitoring stations were established at these same exterior locations, as well as at inflows, outflows and interior spillways (Figure 19). These new stations are supplementary to the stations used for ongoing compliance monitoring conducted by the

South Florida Water Management District (SFWMD) (SFWMD 2003) and the USACOE (USACOE 2003). In the startup phase of the basin operation (summer 2002), these stations were periodically sampled, and in some instances, water quality data was logged by insitu analytical equipment (Ch2M Hill, 2002i). However, since summer, 2002, very little data have been acquired due to a combination of dry conditions and financial limitations (Ch2M Hill 2003b, 2003c).
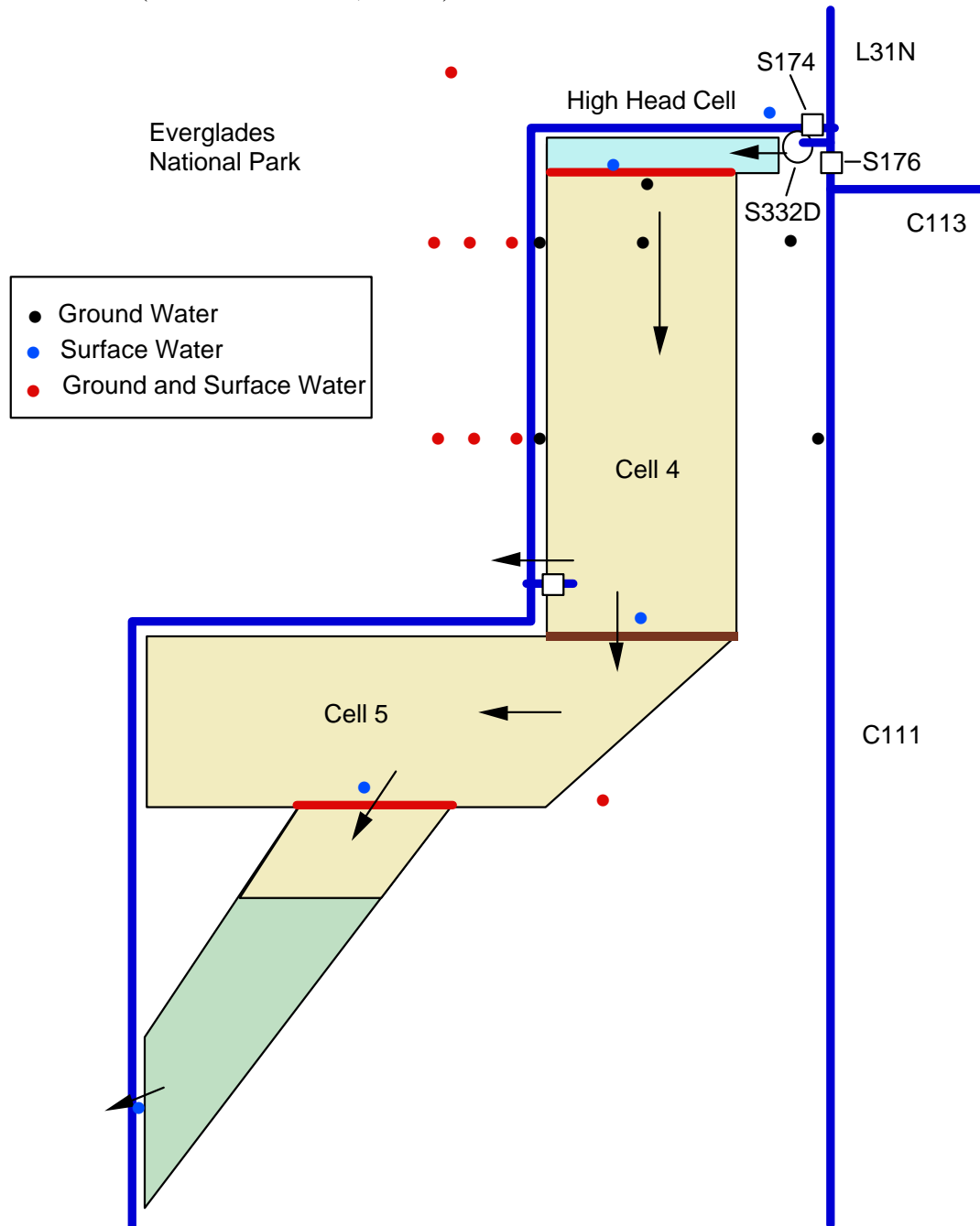

Figure 19: Locations of groundwater and surface water monitoring stations. (Not to scale)

6. The Current Conceptual Plan for the Field Scale R&D Project

The earliest versions of proposed Frog Pond water quality research projects were conceived before the S-332D pump station or the S-332D detention area were in place (USACOE 1996, 1997, 1998, 2000c). As a consequence, these early project proposals were constrained by the perceived limitation (new pumps) on available flows, and were therefore of relatively modest size (1- 10 acres). With the advent of the S-332D pump station, the high head cell and detention area, this flow limitation was removed, and a scaled up version of the water quality research project came under consideration. After several planning meetings and alternatives evaluations, a consensus plan for the field scale R&D project was identified (CH2M Hill 2003a).

In the first week of January 2003, a working group agreed upon a design that best fit the site constraints and goals of the project. The consensus plan contemplates partitioning Cell 4 in the S-332D detention area into three parallel sub-cells, oriented north-south, and all conveying water southerly to Cell 5 of the S-332D detention area (Figure 20). The easterly sub-cell is to be relatively small, ca. 20% of the Cell 1 total acreage. This easterly sub-cell was conceived to remain wet nearly 100% of the time, and be capable of variable depth and flow. The central sub-cell was also to be relatively small, ca. 20% of the Cell 1 total acreage; however, operation was conceived to encompass shorter hydroperiods. The balance of Cell 4, ca. 60%, was reserved to convey the necessary flood control volumes, without any operational constraints that would jeopardize this flood control function for the basin as a whole.
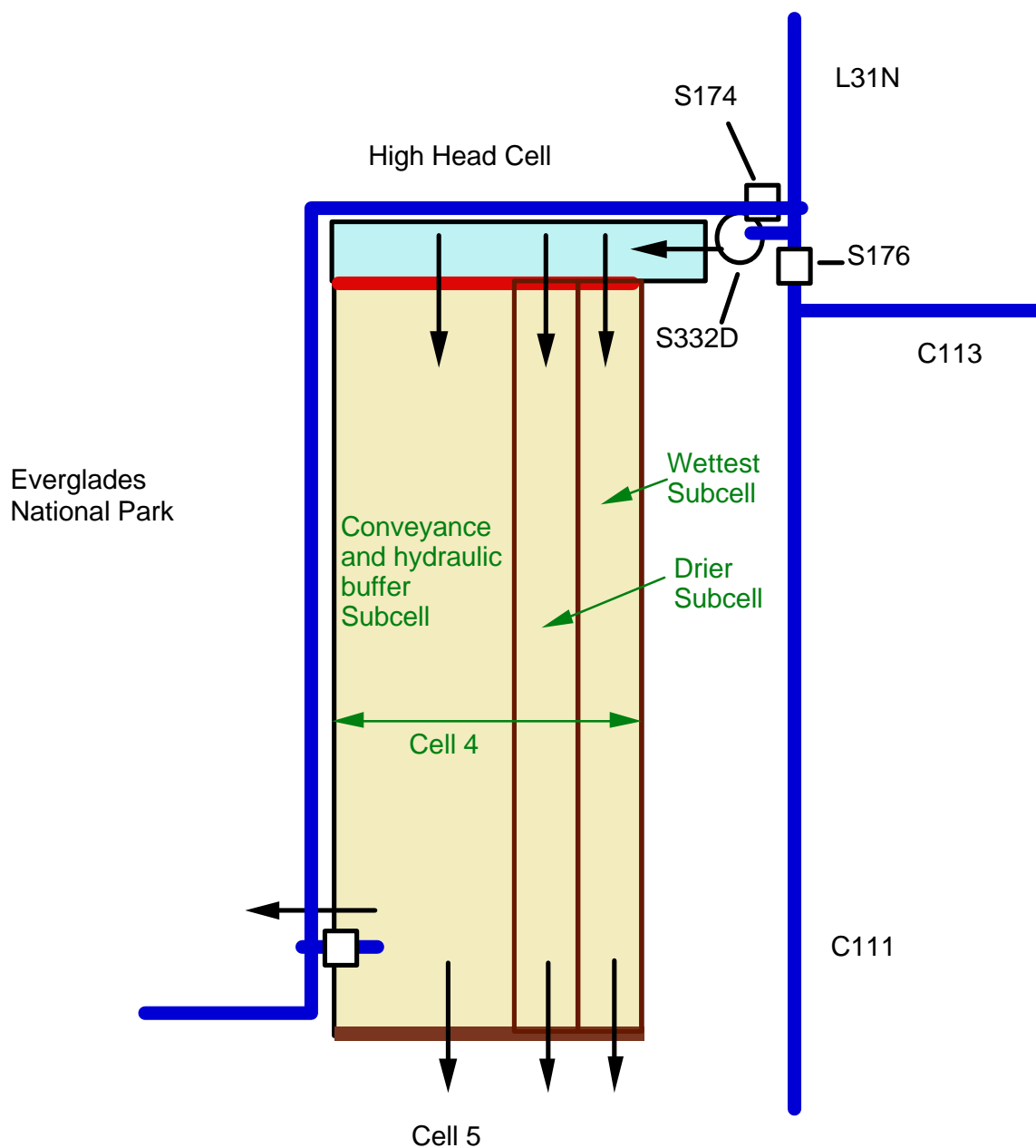
Figure 20. Proposed research and demonstration sub-cells, field scale water quality project. (Not to scale)

As of the time of this writing, ten months after consensus, the USACOE contractor (CH2M Hill) has not been tasked with committing this design to writing.

A plan of study and work plan had been developed concurrent with earlier conceptual designs (CH2M Hill, 2001b). As of the time of this writing, ten months after consensus, the USACOE contractor (CH2M Hill) has not been tasked with preparing a plan of study and work plan associated with the January 2003 conceptual design. The current estimate of the USACOE contractor (CH2M Hill) is earliest completion in 2005. Other similar

projects indicate a startup period of about a year, thus indicating the start of data acquisition in 2006. As a consequence, there can be little or no design guidance from the water quality research project, and operational guidance would be available no sooner than 2007, a year after startup ends.

6.1 Hydraulics and Hydrology

The S-332B, S-332C and S-332D detention areas are intended to infiltrate most of the water pumped into them. The groundwater recharge thus created is intended to flow primarily to the east, with small westerly flows blocking the loss of groundwater from ENP. Early results from these basins indicate that these results are being achieved. Continuing efforts are underway to fine-tune the pumping to prevent surface overflows to the west from the S-332B and S-332C detention areas. The ultimate goal is to prevent overflows to the Park from the S-332B and S-332C detention areas, and to use the flow way at the exit of the S-332D detention area to convey water to the Park.

Infiltration rates in the various basins have been partially quantified. A pump and drawdown test of the S-332B basin indicated water infiltration of about 75 cm per day (Hendren 2000). Preliminary information from the S-332D basin indicates infiltration rates of 30 – 50 cm/d. Those rates are in the expected range. As a result, water detention times in the basins are very short, typically less than one day.

As a second consequence, seepage water returns underground to the east, back into the L-31N or C-111 canals, where it joins southerly flows (Figure 21). Thus water infiltrated in the S-332B detention area may be pumped again at S-332C. Groundwater return flows from the S-332C detention area may then be pumped again at S-332D. Groundwater return flows from the S-332D detention area are not pumped again, but flow south in the C-111, through S-18C, and into ENP through the degraded levees to the north of the Park eastern panhandle.

As a third consequence, water pumped to the high head cell of the S-332D detention area is lost, in major part, by infiltration back north into the L-31W canal (CH2M Hill, personal communication) (Figure 21).   That canal acts as a spreader into ENP. The underground flow path is very short, and as a consequence, this head cell infiltrate reappears as groundwater discharge, presumably of essentially of the same quality as the pumped water.

As a fourth consequence, easterly groundwater flows from the S-332D detention area have been identified as a potential cause of flooding of agricultural lands to the south and east of the S-332D detention area (Muñoz-Carpenter and Li, 2003).
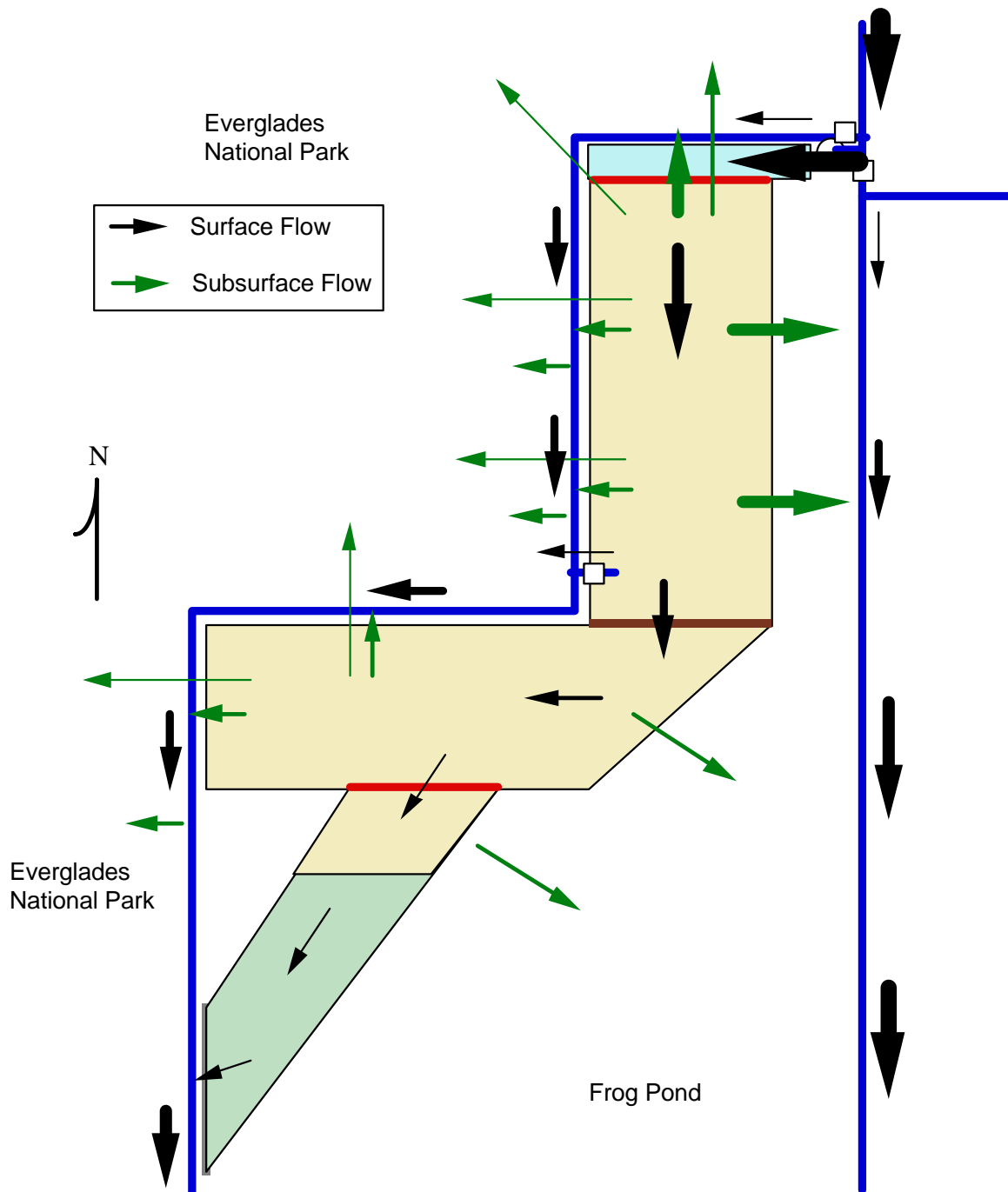
Figure 21. Probable flow directions in the vicinity of the S-332D detention area. Arrow sizes indicate rough flow magnitudes under basin full and overflowing conditions. (Not to scale)

TP concentrations have been quite low in the pumped discharges into the various detention areas, typically in the range of 5 – 8 ppb (USACOE 2003; Bechtel et al 2003). TP concentrations measured in the vicinity of the outflow weir from the S-332B detention area were generally lower than inflow concentrations during its infrequent overflow events in 2001-2003 (Figure 22). It is possible that these reductions reflect

physical mechanisms (settling, adsorption), as opposed to biological uptake (USACOE 2003). Basin concentrations were much higher (10 – 300 ppb) during periods without overflow, which accounted for most of the time and seepage losses. Depending upon seepage direction and P transformations in groundwater, seepage outflows from this basin and others in the C-111 project may impact adjacent ENP marshes. Unless specific and predictable removal mechanisms are identified, the detention areas should not be relied upon to provide significant water quality treatment. Given the uncertainties and risks, prudent operation of the system would minimize inputs to the Park in forms of seepage or direct overflow.
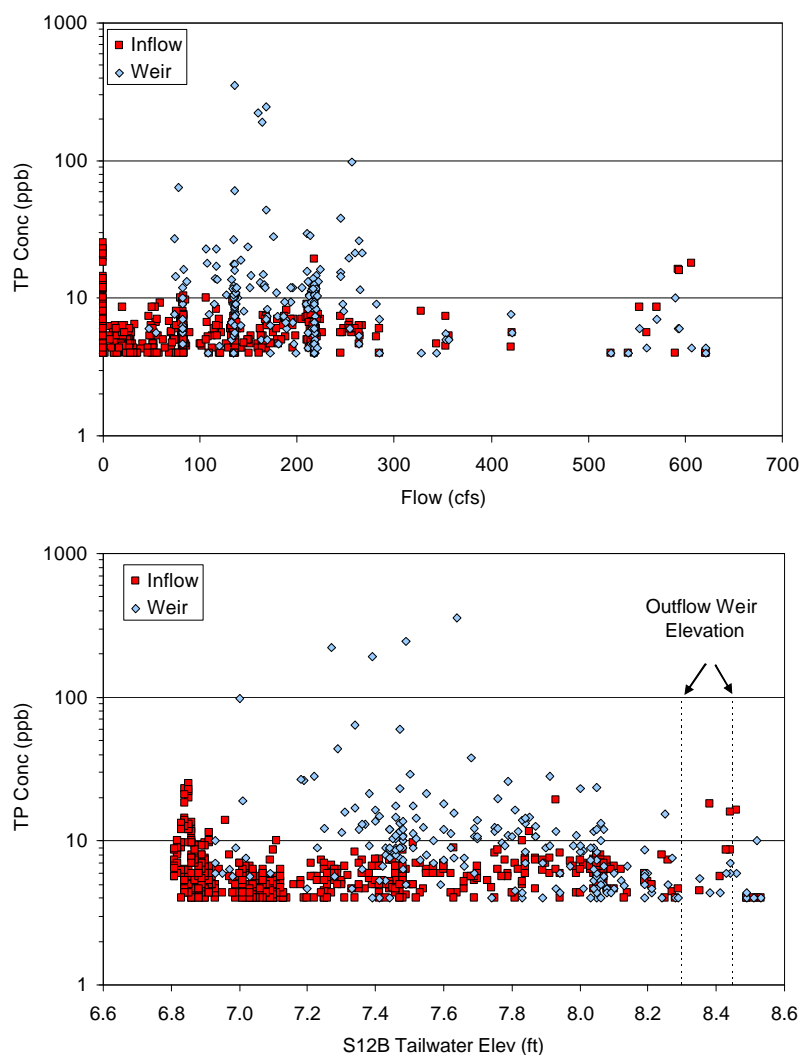
Figure 22. TP concentrations at inflow and outflow from S-332B detention area. Y axis = Total P concentration (ppb). X-Axis = S332B flow, cfs (Top), = S-332B tailwater elevation, feet (bottom). Red squares = S-332B pump station. Blue diamonds = detention basin adjacent to overflow weir. Assuming that S-332B tailwater stage is representative of water level adjacent to the weir, surface overflow occurred when tailwater stage exceeded the weir elevation, which ranged from 8.3 – 8.45 ft. Data from Corps of Engineers, 2001-2003.

There is therefore concern that the infiltration concentrations are higher than the concentrations of the inflows and outflows. In compensation, particulate P may be filtered in the top soil layers, and not reach groundwater. In any case, because most of the water infiltrates, most of the P also infiltrates.

Infiltrated P is taken as a credit by USACOE (USACOE, 2003). Because of large amounts of infiltration, large percentage mass removals are claimed for the detention basins. There are three problems associated with this interpretation.

1. The quality of the infiltrated water is not as good as the inflow or outflow water quality.

2. Much of the water from each basin infiltrates to the east and rejoins canal waters, only to be pumped again into another basin (USACOE, 2003). This picture seems realistic, although no supporting model calculations are given or referenced. It is inappropriate to take "credit" for load removed, when a goodly portion of that load reappears later in the system. Such repeated re-pumping, with the infiltration credits, could lead to greater than 100% load reduction, when in fact no phosphorus has been removed at all.

3. Infiltration flows may be mobilizing deep porewater phosphorus, and moving it both east and west, underground, to adjacent canals and the Park, respectively. Preliminary evidence of this antecedent P pool and its subsequent movement during basin operation has been documented for the S-332B detention area (CH2M Hill, 2002i).

Potential mechanisms for water quality enhancement in the cells include (1) biological uptake from surface waters; (2) particle settling from surface waters; and (3) filtration/adsorption from seepage flows returning to the L31N/C111 canals or entering the adjacent ENP marsh. Although a substantial monitoring effort has been undertaken by the USACOE (Anamar, Inc, 2003) and recently by SFWMD (2002), currently available water quality and hydrologic data are insufficient to evaluate the water quality dynamics of the detention areas and to quantify flows and concentrations in surface and groundwater outflows from the detention areas.

Water quality (phosphorus) modeling has been conducted using the Dynamic Model of Stormwater Treatment Areas (DMSTA) (Walker and Kadlec 2002). Flow and concentration data were available for the S-332B detention area starting in the year 2000, but TP concentration data were deemed reliable only after November 2000. Model runs were configured to match the observed seepage losses, by adjusting the seepage loss coefficient to match observed stages and flows. The P removal parameters were selected as those derived from 29 other periphyton-dominated treatment wetlands (Kadlec and Walker 2003). The settling rate thus selected was 31 m/yr, for a base irreducible TP concentration of 4 ppb. A good correspondence between model and observed performance was found, with both modeled and measured removal of 25% of the inflow TP load was discharged as surface overflow, 70% was lost to seepage, and 5% was retained in the system. 25% of the inflow TP load was discharged as surface overflow,

70% was lost to seepage, and 5% was retained in the system. However, the concentration reduction achieved for overland discharges to ENP was less than one ppb, and is forecast to be on the order of 5 – 15% for incoming concentrations of 6 – 20 ppb.

Two caveats must be considered in connection with DMSTA forecasts: the effects of dryout, and filtration of particulate phosphorus upon infiltration. Dryout can possibly cause mineralization and mobilization of stored P, which may re-dissolve upon rewetting. This potential process would decrease the small removal potential of the detention areas. Conversely, DMSTA presumes that the TP concentration in infiltrated water is the same as that in the surface water in the impoundment. Physical filtration may, however, remove the particulate fraction before infiltration.

The early performance of the S-332B and S-332D detention areas has indicated that hydraulic functions are very likely to be successful in preventing underground water flow from ENP to the east. However, issues of flooding in the southern Frog Pond remain unresolved.

Currently, it appears that there is no P water quality problem in the C-111 surface waters entering or leaving the S-332B and S-332D detention areas. The early performance of the S-332B and S-332D detention areas indicates that most of the water infiltrates, carrying a proportionate amount of P with it. Performance of the S-332B and S-332D detention areas indicates little change in surface water TP concentrations. However, the fate of infiltrated water is uncertain, with the possibility of significant short-circuit leakage from all detention basins to ENP, especially to the -L31W from the S-332D head cell. Additionally, water is likely to "spiral" in a southerly direction, due to pumping and easterly backflow accompanying southerly canal flow in the L-31N and C-111. This process would ultimately deliver water to the panhandle of ENP, with an unknown degree of P removal in subsurface portions of the flow path, and with unknown sustainability of any such removals.

The C-111 field scale water quality project of the USACOE has been a long time in planning; there have been many iterations since 1996. During that seven-year period, no project design or project plan of study has been finalized. The project is currently stalled, and has been for a period of one year, thus creating serious doubts that it will ever come to fruition. However, the early performance of the S-332B and S-332D detention areas, together with forecast modeling, indicates that very little surface water quality improvement, in terms of phosphorus removal, can be expected.

7. Compliance with Consent Decree Inflow Phosphorus Limits

The State/Federal Consent Decree (Hoeveler 1991) sets yearly limits on inflow TP concentrations to Shark Slough (effective October 2003) and to the Taylor Slough/Eastern Panhandle basins (effective December 2006). This section discusses 1994-2003 data in relation to the limits for each basin (Figures 23 and 24, respectively). While the limits were not effective during this period, the data provide a basis for assessing current status and potential impacts of IOP and other factors that may influence future compliance. For consistency with the above analyses, the procedures used in

computing basin flow-weighted-mean concentrations differ slightly from those that will be used in compliance determination with respect to computation of basin totals (combining annual flows and loads across structures vs. combining flows and loads on dates when concentrations were measured) and water year definition (May-June vs. October-September).   Conclusions are not sensitive to these differences, however.
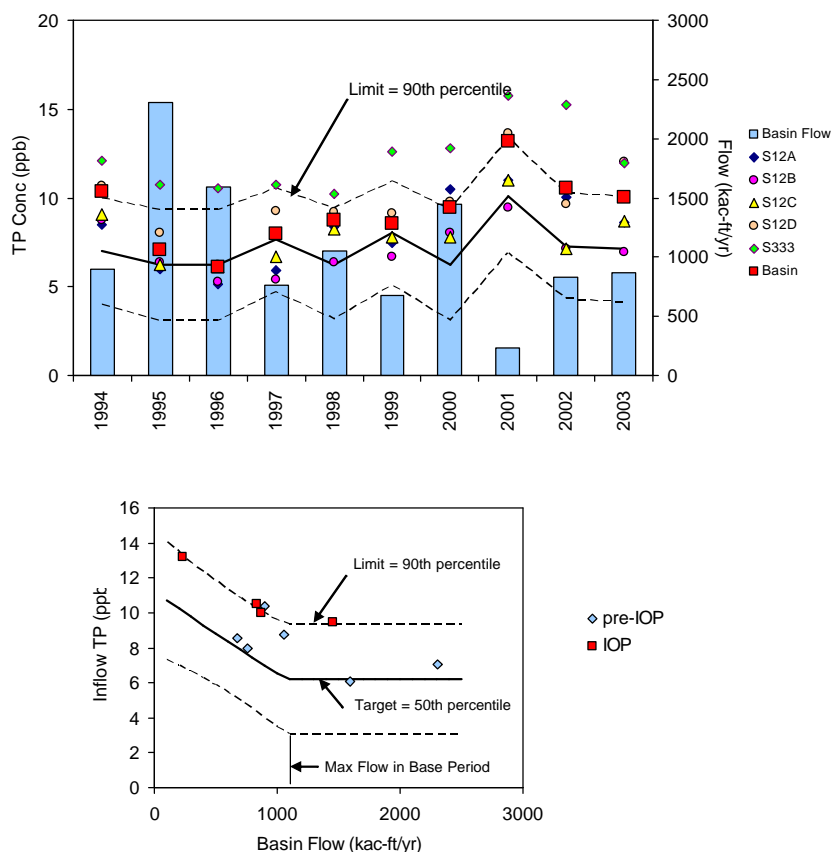
Figure 23. Consent Decree inflow TP limits for Shark Slough. Water Years 1994-2003 (June-May). Red Squares = basin flow-weighted mean (S-12X+S-333-S-334). Other symbols show results for individual structures (not used in testing compliance).   Bottom chart shows interim limit (90th percentile of 1978-1979 data) and targets as a function of basin flow (S-12X+S-333). The interim limits apply to the basin flow-weighted-mean concentration and is effective October 2003.
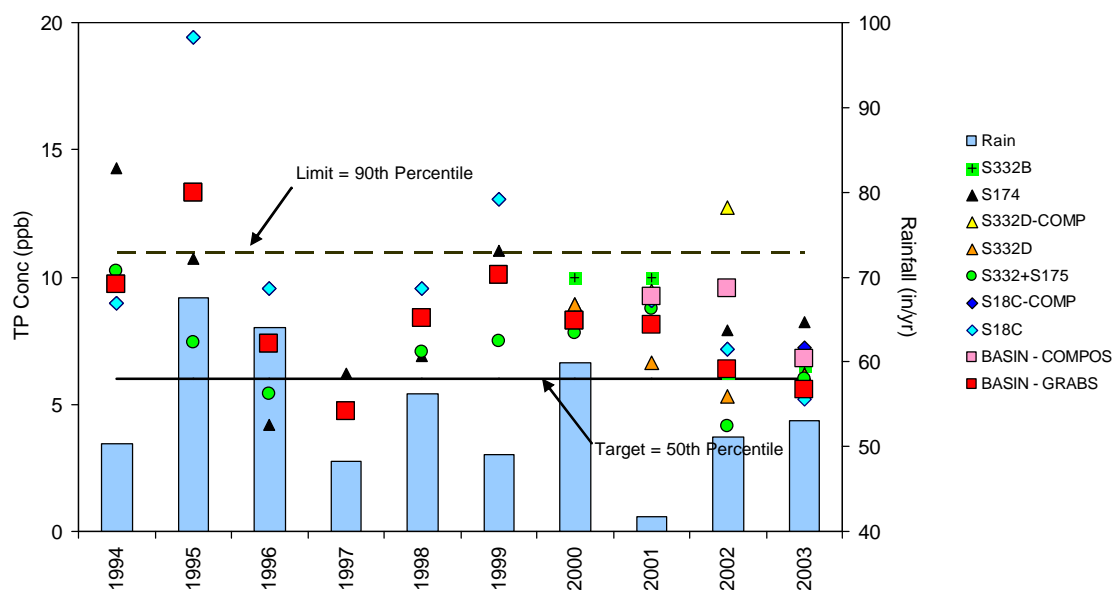
Figure 24. Consent Decree inflow TP limits for Taylor Slough and Eastern Panhandle. Water Years 1994-
2003 (June-May). Red Squares = basin flow-weighted mean using grab samples (S18C+S-332+S-175 in
1994-1999 and S-18C+S-332D+S-174 in 2000-2003). Pink squares = basin flow-weighted mean using
composite samples for S-332D & S-18C. Other symbols show results for individual structures (not used in
testing compliance). The long-term yearly limit of 11 ppb (effective 2006) represents the 90th percentile of
1983- 1984 data and is applicable to the basin flow-weighted mean.
The target (6 ppb) represents the 50th percentile

Figure 23 shows yearly Shark Slough inflow concentrations in relation to interim limits
computed from basin flow. The flow dependence reflects a negative correlation between
concentration and flow in the 1978-1990 data used to derive the limits (Walker 1999b,
2002). The flow adjustment is analogous to the rainfall adjustment used in the above
analysis. The objective of establishing the limits was to restore 1978-1979 water quality
conditions. Consistent with the above results, there was an apparent increase in
concentration (2.0 ± 0.8 ppb) at a given flow after IOP implementation. In 1994-1999,
concentrations varied between the target and limit, which reflect the 50th and 90th
percentiles of 1978-1979 concentrations. After 1999, concentrations were consistently
close to the limit. The apparent increases are independent of whether the hydrologic
adjustment is based upon flow or rainfall, as further demonstrated in Figure 16. As
discussed above, the increases may be related to changes in the WCA-3A regulation
schedule under IOP and/or trends in phosphorus loads to WCA-3A from specific basins.

Figure 24 shows yearly inflow concentrations for the Taylor Slough/Eastern Panhandle
basins in relation to the 11 ppb limit. The limit is fixed because there was no apparent
correlation between flow and concentration in the 1983-1990 baseline data.

Concentrations generally fluctuated between the target and limit lines in 1994-2003, with no apparent change after IOP implementation. The 11 ppb limit was exceeded in one year (1995), which also had the highest rainfall and the highest concentration at S-18C. While recent data suggest an optimistic compliance forecast, concentrations in 2000-2003 were not representative of wet years or future conditions with the C-111 buffer project in full operation.

Changes in water delivery to Taylor Slough under IOP have introduced new complexities into the tracking of compliance in this basin. Basin flow-weighted concentrations were originally computed using grab sample and flow data from structures discharging directly into the Park (S-18C, S-175, and S-332). Since deliveries through S-332 and S-175 were stopped in 2000, compliance has been tracked using data from S18C, S174, and S332D (SFWMD 2003). The S-174 and S-332D flows enter the L-31W and S-332D detention areas and do not enter the Park directly. This procedure is used because the monitoring systems for tracking direct inflows to the Park in this region via overflow from L-31W, overflow from detention areas, and seepage are not in place. New discharges through S-332B and S-332C, which may increase TP loads to the Park via overflow and/or seepage from the detention areas, are ignored altogether in tracking compliance. P initially stored in the soils of the detention areas may be stripped and transported into the adjacent marsh via overflows or seepage.

With operation of the new pump stations (S-332B, C, D) and lowering of L-31N/C-111 canal stages to provide increased flood control for adjacent developed areas, the current procedure of utilizing grab samples exclusively in tracking compliance may not provide an adequate estimation of ENP inflow concentrations or loads under current conditions. As illustrated in Figure 20, flow weighted means for S-332D, S-18C, and the basin whole are higher when composite samples are utilized in the calculations. These are significant issues that need to be resolved in tracking future compliance, supported by data from an expanded monitoring program recently implemented by SFWMD (2002).

8. Assessment of Interim Operational Plan – Downstream Marshes

The focus of this analysis is on long-term datasets for water quality (including salinity), surface water levels, and macrophyte primary productivity at an array of sites in the Southern Everglades. First, below, is provided a brief description of our array of sampling sites. The C-111N sites and data are not directly related to ISOP/IOP and will not be presented in this analysis. Additionally, in late 2002, water quality, soils, and plant community monitoring at the S-332B detention area outfall as well as soils and plant monitoring at the S-332D inflow, were initiated. One figure from the Year 1 Annual Report is presented in this analysis.

All data interpretations in this assessment are based on the project schedule presented in Mitchell-Bruker and O'Connell (2003). Our understanding of this schedule is that Test 7 was in effect through 1999, ISOP was in effect for only 2000, ISOP 2001 was in effect from January 2001 through June 2002, and IOP (the current interim plan that will replace

Modified Water Deliveries Project when it is complete) has been in effect since June 2002.

8.1 Southern Everglades Site Descriptions

The Southern Everglades Research and Monitoring Network includes a network of sites located along transects oriented both parallel to and normal to flow in both the C-111 Basin and Taylor Slough. In some situations, sites are also part of the FCE LTER Network. Where this is the case, they carry two names (the second being a "TS/Ph" name that stands for Taylor Slough/Panhandle; Table 1). In the C-111 Basin, we maintain 2 transects: One anchored at the western edge of the levee removal zone (site W-1, or TS/Ph-4) and terminating at Trout Creek in NE Florida Bay (TC; TS/Ph-8; 5 sites total), and the other anchored at the eastern edge of the levee removal zone (E-1) and terminating south at the ENP boundary (2 sites total). Our Taylor Slough sampling involves a primary transect down the center of the slough [and parallel to flow] that is anchored at the water inflow point along the L-31W just north of the S-332 pump structure (S-332D; TS/Ph-1a) and terminates at the mouth of Taylor River, in Little Madiera Bay (TR; TS/Ph-7; 7 total sites). At three points along this primary transect, we quantify macrophyte primary production along sub-transects oriented normal to flow. The first is just north of the Main Park Road (UE, UC, and UW), the second is in the Madiera Ditches area (ME, MC, and MW), and the third is along the northern edge of the estuarine ecotone (LE, LC, and LW).

8.2 Freshwater Marsh Water Levels

Water levels in the C-111 basin generally show an inundation pattern typical of intermediate hydroperiod marshes that are dry 5-6 months per year. Our west transect data show an atypical pattern in 1998 though, which we attribute to the unusual conditions that resulted from a strong El Niño that year—the 1998 dry season was particularly wet, while the 1998 wet season rains were approximately 2 months late (Figure 25). 1999, the last year of Test 7, was a relatively wet year in the C-111 basin, as was 2001 (our data for 2000 are incomplete; Figure 25). Precipitation was below average in 2001, and we attribute the more average inundation regimes seen in the C-111 basin on this year to ISOP re-routing of water from Shark Slough to the southern Everglades. In 2000, we installed rain gauges at our autosampler sites (Figure 25). We investigated relationships between daily rainfall and change in marsh water level for that day using data from our W-1 (TS/Ph-4) and W-2 (TS/Ph-5) sites, and found a strong disconnect between local precipitation and marsh hydrology. Although both regressions were significant ($p<0.001$, n=94; $p<0.001$, n=84, respectively), we found that local rainfall explained only 20% and 27% of water level change at these two sites, respectively
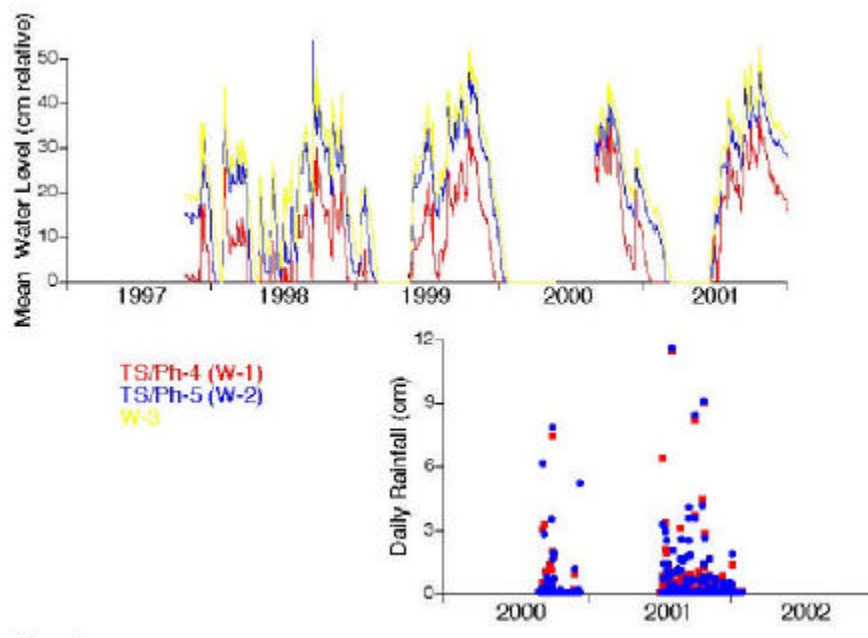
Figure 25 Caption for Figure 1 – Lower C-111 Marsh (west transect) Water Levels during pre-ISOP/IOP (1997-1999) and ISOP/IOP (2000-2003) and Daily Rainfall during ISOP/IOP. 10 centimeters = 4 inches.

Water level gauges were installed at all Taylor Slough water quality sites in mid-1999. These data show a consistent pattern of the most dramatic water level fluctuations at the Main Park Road site, closest to manipulated water inputs; most of this signal is damped by mid-slough (Figure 26). The transition from Test 7 in 1999 to ISOP in 2000 appears to have generated a very abrupt wet-dry season transition in upper Taylor Slough. Marsh water levels remained high well into the 2000 dry season, then fell very quickly (Figure 1). Marshes in central Taylor Slough remained inundated for most of this dry season. While this may be a result of Hurricane Irene in 1999, we suspect that dry season 2000 structure management may also have played a role. In 2000, however, the pattern was quite different. Wet season water levels began to drop
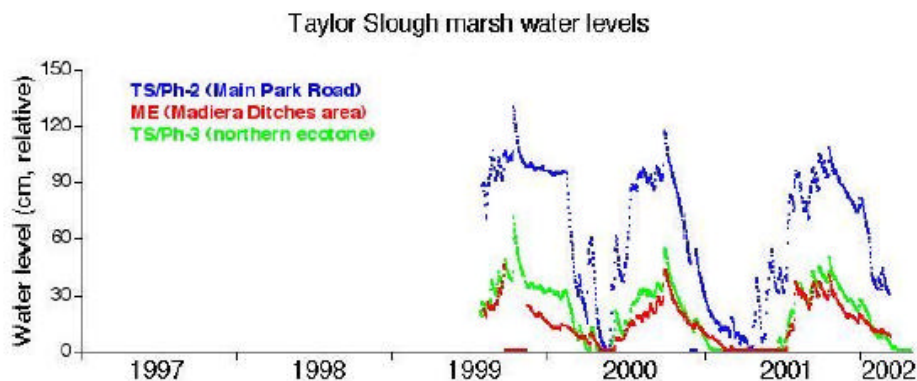
Figure 26 Caption for Figure 2 – Taylor Slough Marsh Water Levels from pre-ISOP/IOP (1999) and ISOP/IOP (2000-2003). 10 centimeters = 4 inches

in October, and Taylor Slough was dry for many months into the 2001 dry season. As we note above, 2001 was a dry year, and the 2001 dry season in Taylor Slough shows this. However, hydroperiods were actually longer in the 2001 wet season compared to 2000 (Figure 26). This was likely at least partially due to the re-allocation of water from Shark River Slough to the Southern Everglades during this time.

8.3 C-111 Basin Water Quality

Nutrient loading is a concern in any Everglades wetlands receiving canal inputs. It is also important to understand how Everglades wetlands process nutrient inputs. Nutrient load is a product of water flux and nutrient concentration. Any management approach that increases water inputs has the potential to increase nutrient loads if concentrations are excessive. For this reason, we monitor water quality along transects parallel to flow in both the C-111 basin and Taylor Slough. In the C-111, our TP data from the west transect (which has a lower bank elevation and thus receives canal water for longer each year than the east transect) show consistent uptake of TP by the freshwater marshes, and typically low TP concentrations at the mangrove site end member as well (Figure 27).

Figure 27. Nutrient Concentrations in Lower C-111 Marsh (west transect) during pre-ISOP/IOP (1997-1999) and ISOP/IOP (2000-2003). (1 μM TP = 31 ppb TP)/(100 μM TN = 1400 ppb TN).
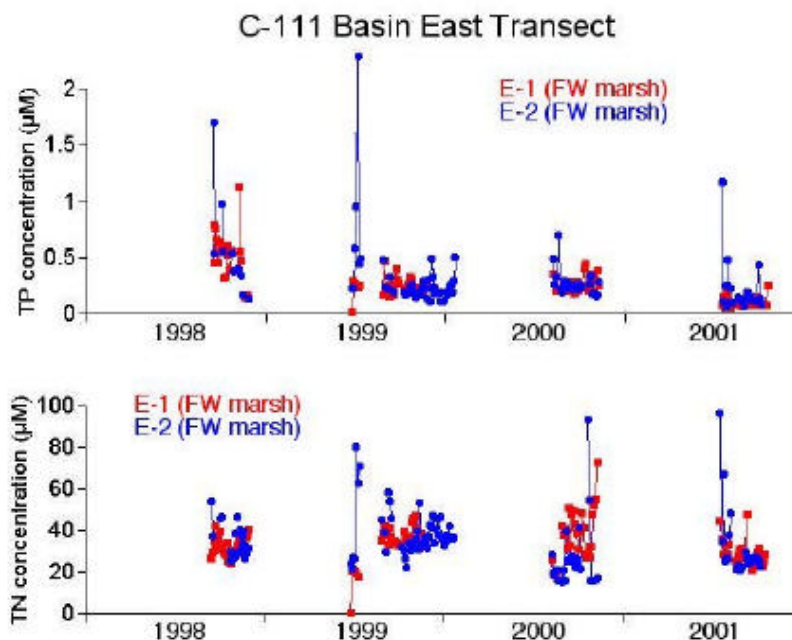
Figure 28. Nutrient Concentrations in Lower C-111 Marsh (east transect) during pre-ISOP/IOP (1997-1999) and ISOP/IOP (2000-2003). (1 µM TP = 31 ppb TP)/(100 µM TN = 1400 ppb TN).

The same P uptake pattern occurred along our east transect (Figure 28). Since 1998, we have seen few isolated incidents of high TP canal water entering the C-111 basin. 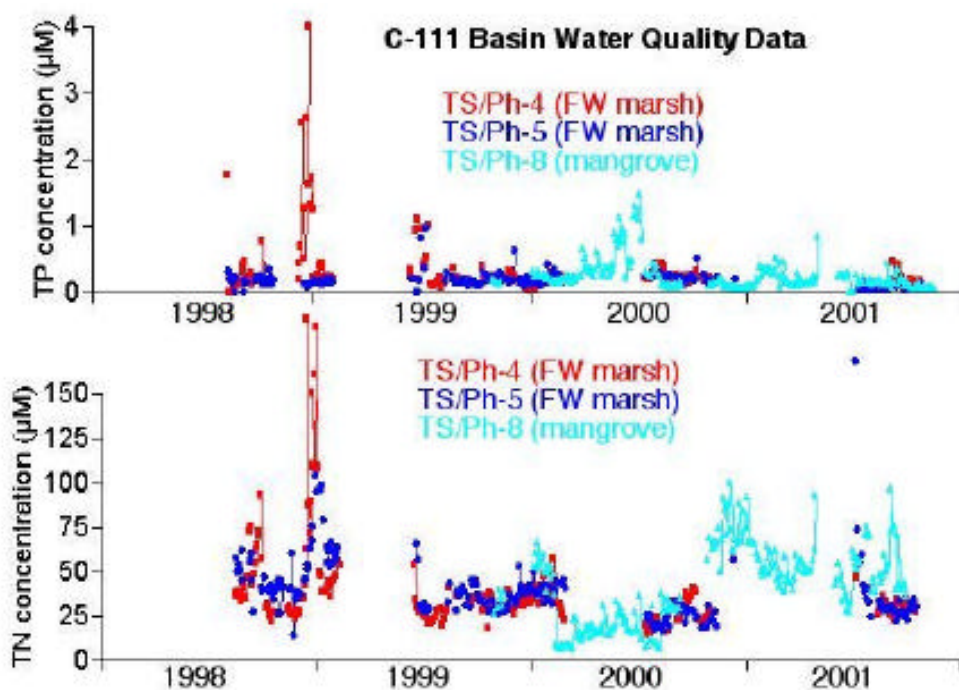The most dramatic was a nearly 2-week time period in December 1998 in which TP concentrations at W-1 were high (1-4 µM (31-124 ppb TP); Figure 27). Canal levels were already below bankfull at our east transect at this time. At the onset of the wet season, when canal water first entered the marsh, we often saw elevated TP concentrations (~ 1 µM (31 ppb TP)). This phenomenon only occurred in 1999 at W-1 (Figure 28) but occurred to some degree in 2000, and 2001 as well at the E-1 site (Figure 28). Mean TP concentrations in canal water entering at our W-1 and E-1 sites, from 1998 – 2001, were ~ 8µM (248 ppb TP). At this concentration, even increased water inputs will likely not generate ecologically significant TP loads. In composite samples collected in C-111 marshes since 1998, TP has seldom exceeded 10ppb, and with the exception of certain events there is some evidence of a 6-year downward trend of TP in the water entering C-111 marshes.

Total Nitrogen (TN) concentrations in C-111 water entering at our transects were typically in the 40 µM (560 ppb TN) range (Figures 27 & 28). TN concentrations were consistently higher at W-1 than at E-1 in 1998, and the December 1998 event that caused high TP concentrations also showed high TN concentrations (Figure 27). Total N concentrations were much more stable from 1999 to 2001, and even appeared to be lower at W-1 than at E-1 for much of the 2000 wet season. We have no explanation for this pattern. As with TP, we observed early wet season TN spikes at W-1 in 1999 and at E-1 in 1999 and 2001, suggesting a "first wetting" enrichment phenomenon that was short-lived in all cases (Figures 27 & 28). Often, downstream TN concentrations (at W-2 and

55

E-2) were higher than at the canal-side sites, suggesting an export of TN from the marsh to the overlying water. Rudolf Jaffé (FIU) has demonstrated that these marshes often produceDON in the form of proteins and amino acids, substantiating this phenomenon. In many situations, wet season mangrove TN values are higher than freshwater marsh concentrations (Figure 27), suggesting continued organic N production as water flowed into Florida Bay. The dry season TN patterns at the TS/Ph-8 mangrove site are very curious, though: In 2000, dry season TN concentrations were quite low while in the 2001 dry season they were up to 3 times higher. This is not easily explained by wet season water management. In composite samples, total nitrogen concentrations are considerably lower than Taylor Slough marshes (350 to 420 ppb), and the data show a clear downward trend in total nitrogen concentrations. At this time, there is no evidence of water quality impacts on C-111 wetlands and since these wetlands are well north of ENP wetlands there can be no evidence of ISOP/IOP water quality problems on Eastern Panhandle wetlands.

8.4 Taylor Slough Water Quality

Taylor Slough TP concentrations typically ranged from 0.25 – 0.5 µM (7.8 – 15.5 ppb TP) at the sites closest to the L-31W canal. Notably, the TS/Ph-1 site was located just west of a low berm along the west side of the canal, roughly 1 km north of the S-332 pump while the S-332 site was located about 200 km SW of the S-332 pump in a relatively impacted area. During 1999, when the S-332 was still pumping, TP concentrations occasionally exceeded 0.5 µM(15.5 ppb TP), and in the first 1-2 months of 2000 concentrations were consistently high (Figure 29). Wet season samples collected from 2000 – 2002 from our S-332 site were less likely to have TP concentration spikes, and in nearly all cases simultaneous samples from the TS/Ph-1 canal-side site had markedly lower TP content than did S-332 samples. By the TS/Ph-2 site at the Main Park Road, TP concentrations were reduced—often to <0.25 µM (7.8 ppb TP)—and we never saw a TP value above 0.25 µM (7.8ppb TP) at the southern extreme of Taylor Slough (TS/Ph-3; Figure 29). TP concentrations were often higher in the mangrove ecotone than in the freshwater marshes of Taylor Slough, particularly during the dry season when Florida Bay is the primary influence on this region (Figure 30). In

Figure 29. Nutrient Concentrations at Taylor Slough Freshwater Marsh Sites during pre-ISOP/IOP (1997-1999) and ISOP/IOP (2000-2003). (1 µM TP = 31 ppb TP)/(100 µM TN = 1400 ppb TN).

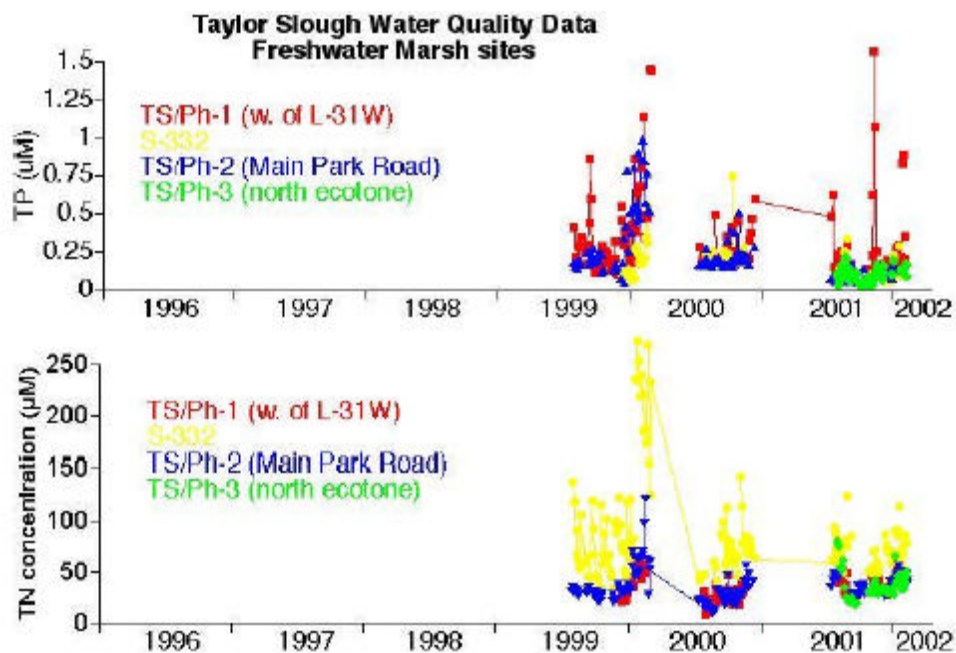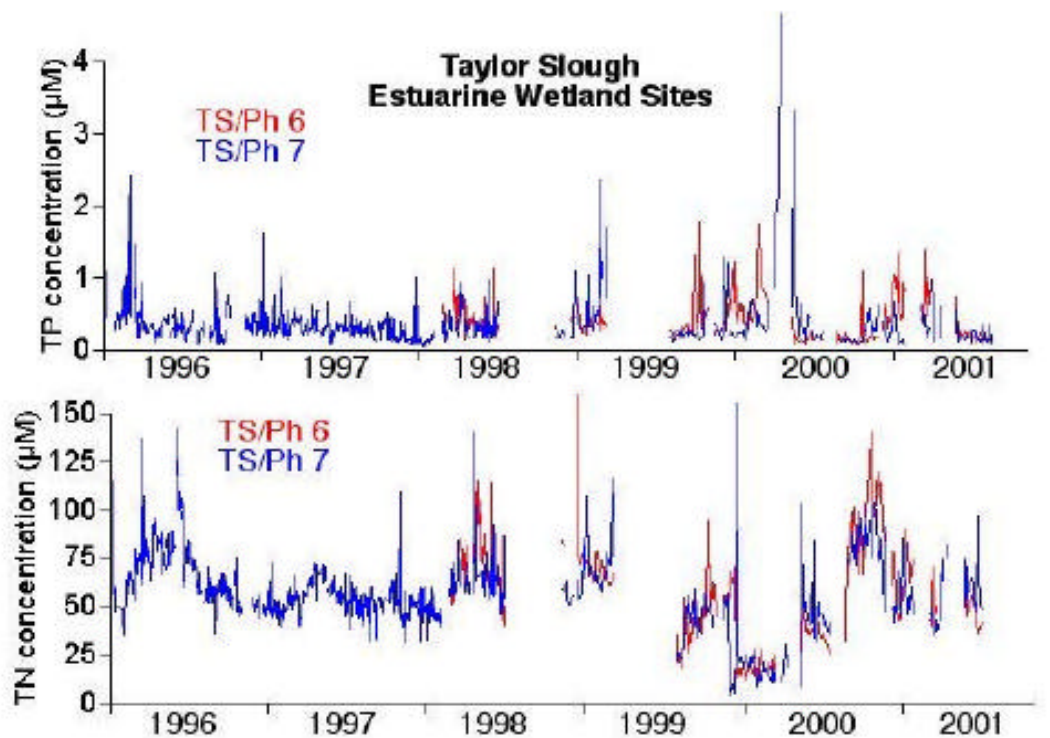Figure 30 Nutrient Concentrations at Taylor Slough Estuarine Wetland Sites during pre-ISOP/IOP (1997-1999) and ISOP/IOP (2000-2003). (1 µM TP = 31 ppb TP)/(100 µM TN = 1400 ppb TN).

most cases, TP spikes of 1.0 µM(31 ppb TP) or more occurred at TS/Ph-6 or 7 during the dry season, when connectivity with upper Taylor Slough was minimal. Interestingly, we saw higher TP concentrations at these 2 sites during the 1999 wet season that coincided with high TP at the upstream freshwater sites (Figures 29 & 30). Further analysis will allow us to estimate if these concentration peaks could represent the same high nutrient water parcel moving south through the slough. In upper Taylor Slough marshes during ISOP/IOP, there were regular events in which TP concentrations exceeded 15 ppb. Furthermore, there were a number of times in late 2003 where the water entering this marsh from L-31W canal via the levee scrape-down area just north of S-332 had TP concentrations above 30 ppb.

Total Nitrogen (TN) was surprisingly high at our S-332 site when compared with either the TS/Ph-1 site or the downstream TS/Ph-2 site (Figure 29). This pattern was particularly strong during 1999, when the S-332 pump was still operating under Test 7. There is some indication that S-332 TN concentrations slowly declined through 2000 into 2001. It is not clear, though, if this N is a canal water signal or is being generated from remineralization processes in the impacted marshes adjacent to the S-332 structure. If high N canal water was entering the park and causing these TN spikes, we would expect to see the same signal at our canalside TS/Ph-1 site. We did not (Figure 29). TN concentrations at interior Taylor Slough sites were typically similar to those in the C-111 Basin—on the order of 40 µM(560 ppb TN). Farther south in the mangrove ecotone, though, TN values were often considerably higher than this (˜ 60 µM(840 ppb TN); Figure 30). From 1996 – 1999, we found a general pattern of lower TN concentrations during the wet season, when upstream Taylor Slough was the primary influence, compared with the dry season, when Florida Bay was the primary influence. In 2000, though, this pattern reversed, and it is not clear which pattern held for 2001 (Figure 30). This TN seasonal pattern switch coincided with the switch from Test 7 to ISOP procedures in 2000, but it is difficult to connect the two. Total nitrogen data from the upper Taylor Slough marshes is even more dramatic. Total nitrogen concentrations during ISOP/IOP have nearly always exceeded 700 ppb and at times have exceeded 1.4 ppm. There is evidence of periodic, even regular nutrient pulses in Taylor Slough wetlands associated with ISOP/IOP water management. While this was not a chronic problem, there is evidence of water quality problems.

9. Soils and Macrophyte Community Sampling

Soil characteristics are excellent long-term integrators of water quality, hydrologic and biogeochemical influences on marsh ecosystems. A stratified random sampling scheme was used to characterize the soil characteristics of ENP marshes receiving water from the S-332B and S-332D detention areas. Many of the soil samples taken during this sampling event had soil P values under 210 micrograms per grams dry weight soil (12 of 24 sites, Figure 31). However, there was a southwest-northeast pattern of soil TP values above 210 micrograms per grams dry weight soil that begins at the south-central portion of the S-332B detention area spillway (Figure 31). This pattern appears to follow the generalized slope of this area and it appears that this is the primary flow path of the

discharge from the S-332B overflow weir. Most of the soil TP concentrations in this "flow path" are not markedly higher than the surrounding marsh, however, there are a few that are much higher; this includes a value greater than 330 micrograms P per gram dry weight at the site closest to the weir (A5) and about 400 micrograms P per gram dry weight at the site furthest from the weir (D2). The D2 site is a deep, slough-like environment where one would expect high P concentrations. However, the "flow path" of moderately high TP concentrations is not a kriging/statistical artifact because this pattern is supported by soil TP concentrations above 210 micrograms P per gram dry weight from 10 to 24 sites.
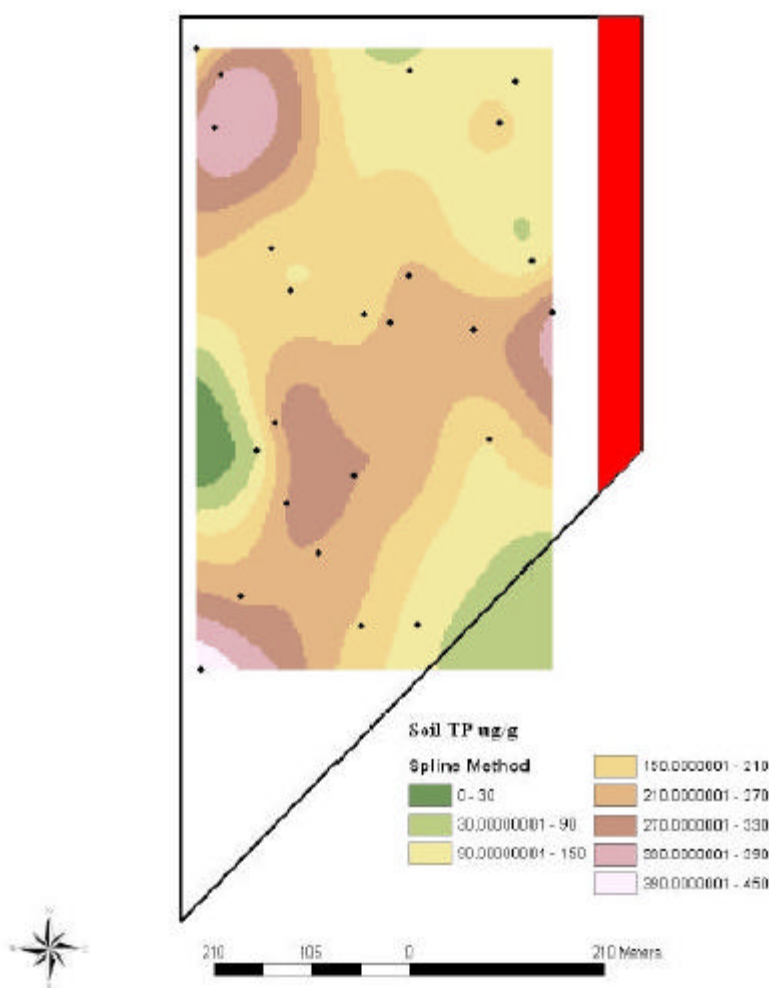

S332-B Soil TP Spatial Interpolation

Figure 31. Soil bulk phosphorous content (ug/g dw) map for the S-332B sampling area. Retention pond spillway is immediately east of the No Sample Zone (showhn in red).

Wetland plants are excellent long-term integrators of hydrologic and biogeochemical influences on these ecosystems. For this reason, we have been quantifying aboveground

net primary production (ANPP) by the dominant macrophyte—*Cladium jamaicense*—at
5 sites in the C-111 basin and at 11 sites in Taylor Slough. ANPP is directly comparable
to similar values from other ecosystems worldwide. In addition, we also quantify a
"production difference", which is simply the difference between end-of-year
aboveground live biomass and the amount of biomass at the beginning of that year. This
calculation requires long-term data, and is both possible and valuable because sawgrass is
a perennial plant (individual culms can live for more than 3 years) and because the south
Florida growing season is year-round. We view this production difference estimate as
equivalent to a species-specific measure of ecological capital. If this value is positive for
several years, then sawgrass is gaining biomass or increasing its ecological capital—
sawgrass is doing well under those conditions. If this value is negative for several years,
then sawgrass is losing biomass in the long term and is living on its ecological capital—
sawgrass is not doing well.

In the C-111 basin, we saw no evidence of a canal fertilization of sawgrass productivity
(Figure 32). While the E-1 site is markedly more productive than the E-2 site, it is also
more productive than the W-1 site and does not show an interannual pattern of increasing
production. In fact, of the 23 annual ANPP measurements shown for this region in Figure
8 (3 sites x 5 years along the west transect, 2 sites x 4 years along the east transect), we
calculated negative values for sawgrass species-specific ecological capital 16 times—11
of which were statistically significant (Figure 32). It appears that, beginning in 1999 or
2000, sawgrass has been losing ecological ground in this landscape. In fact, our data on
plant community composition and hydrology at these sites have shown a significant
negative relationship between sawgrass ANPP and mean annual water level.

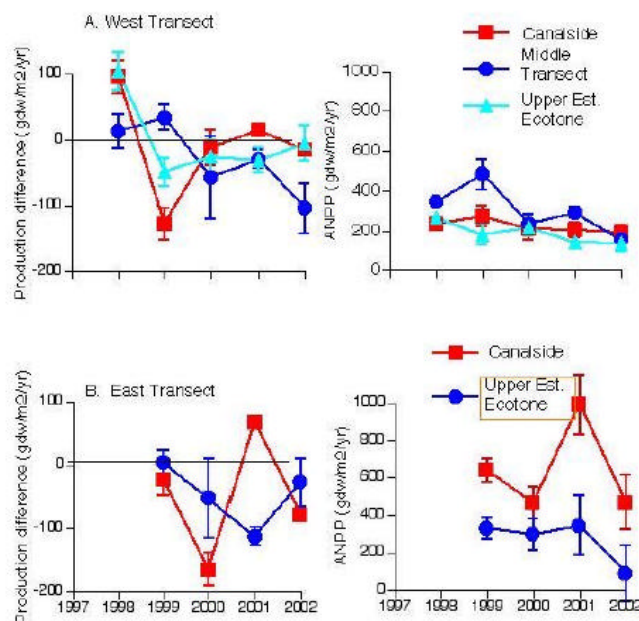Figure 32. Sawgrass (*Cladium jamaicense)* Productivity in Lower C-111 Marsh during pre-ISOP/IOP
(1997-1999) and ISOP/IOP (2000-2003). "Production Difference" is difference between end-of-year
aboveground live biomass and the amount of biomass at the beginning of that year in grams dry weight per
meter squared per year. "ANPP" is aboveground net primary production in grams dry weight per meter
squared per year.

Furthermore, we have also found a significant negative relationship between sawgrass ANPP and *Eleocharis* stem densities in the same plot. Apparently, as the C-111 Basin marshes have gotten wetter with ISOP operations, a transition from sawgrass to slough (*Eleocharis*) plants is occurring, and the species replacement is occurring simultaneously. This transition to a deeper water plant community makes ecological sense, and the fact that it is occurring in real time suggests that, if the transition occurs in the long term, it is unlikely to be ecologically disruptive.

Our experimental design in Taylor Slough was more complex because we are interested in quantifying hydroperiod effects on macrophyte ANPP and plant community structure. In addition to 5 long hydroperiod sites located from the L-31W canal (S-332D, TS/Ph-1b) to the mangrove ecotone (AH, TS/Ph-6), we have three transects oriented normal to flow and along hydroperiod gradients. Notably, the upper (UE, UC, and UW) and middle (ME, MC, and MW) transects are along clear hydroperiod gradients while the lower, ecotone transect site (LE, LC, and LW) all have similar hydroperiod patterns. If hydroperiod or mean annual depth of inundation have changed in Taylor Slough, we should see corresponding responses in sawgrass ANPP and species composition. Our expectations were that, if water got deeper or inundation times lengthened with ISOP/IOP practices, we should see declining sawgrass ANPP at longer hydroperiod sites (UE and ME) and the opposite at the shortest hydroperiod sites (UW and MW). In fact, we found little difference in ANPP along either the upper or middle transects, though there is a suggestion that sawgrass was more productive at the longest hydroperiod site (Figure 33; note that colored symbols correspond to water quality sites, and colors match previous figures of water quality data). At the canalside site and all upper and middle transect sites, we saw a subtle pattern of higher ANPP in 2001 compared with 2000 and 2002.

This follows ISOP activities in 2001 that directed Shark Slough water preferentially to the C-111 basin rather than to Taylor Slough. Productivity patterns at our lower transect, which falls at the northern edge of the mangrove ecotone, were more difficult to explain (Figure 33). The largest interannual change occurred at the central site (LC, TS/Ph-3), where we observed a steady decline in sawgrass ANPP from 2000-2002 and corresponding negative values for species-specific ecological capital. Our southernmost site (AH, TS/Ph-6), at which sawgrass and red mangrove grow in a matrix, shows a pattern that we believe is controlled not by hydroperiod or water depth, but by salinity. The dramatic decline in sawgrass ANPP at this site from 2000-2001 corresponds with a dry season in 2001 that was considerably saltier—both in number of days with salinity >0, mean salinity, and maximum salinity—than 2000 (Figures 33). This may be a result of reduced freshwater inputs to Taylor Slough in 2001 as a result of ISOP management practices.
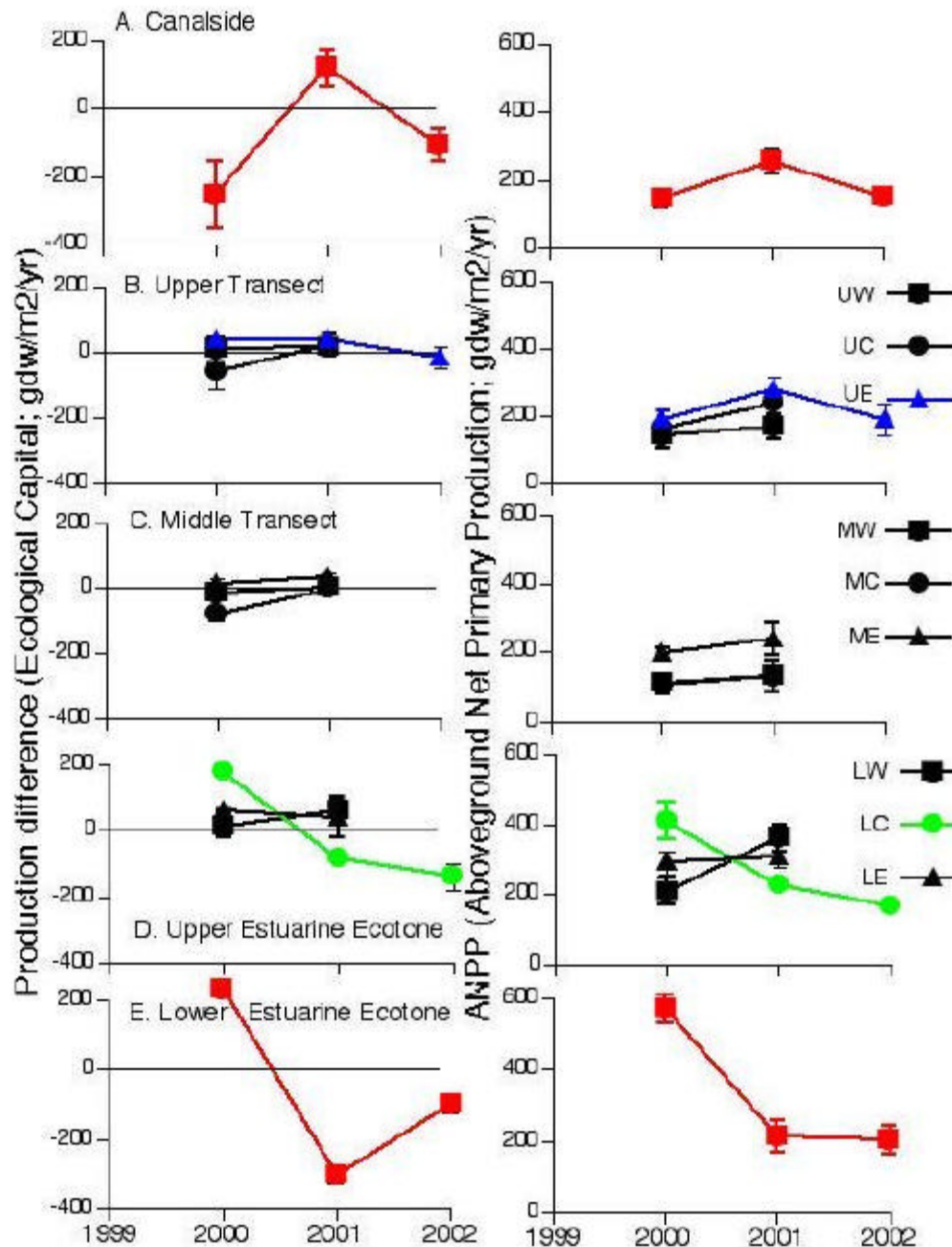
Figure 33. Sawgrass (*Cladium jamaicense*) Productivity in Taylor Slough Marshes during ISOP/IOP (2000-2003). "Production Difference" is difference between end-of-year aboveground live biomass and the amount of biomass at the beginning of that year in grams dry weight per meter squared per year. "ANPP" is aboveground net primary production in grams dry weight per meter squared per year.

10. Operational Recommendations

Based upon the above results, the following recommendations are made for operating the system to minimize water quality impacts with respect to phosphorus:

1. While the apparent increase in phosphorus concentrations in Shark Slough inflows after IOP implementation may be attributed to a combination of factors, there is sufficient evidence linking the increase to the change in WCA-3A regulation schedule to recommend modification of the schedule to avoid drawdown of water levels below Zone E, particularly to stages < 9.5 feet.

2. The historical data do not provide evidence of water quality deterioration in the L-31N/C-111 basin as a consequence of IOP and other changes in system operation that occurred in the 2000-2003 period. Given the historical data limitations and difficulties associated with forecasting effects of C-111 project construction, changes in operation, and changes in land use, future management should be guided by intensive monitoring, data analysis, modeling, and research.

3. Available data do not support reliance on the L-31N/C-111 detention areas for water quality protection. It is recommended that the areas be designed and operated to minimize inputs to the Park in the form of seepage or direct overflow.

4. There is evidence of water quality impact at S-18C by runoff from the C-111E sub-basin, particularly in wet years. It is recommended that plans to provide future treatment of that runoff be reviewed and possibly accelerated.

11. Monitoring and Assessment Recommendations

The following monitoring and assessment recommendations are made to improve understanding of factors controlling water quality and support future management decisions:

1. Further analysis and modeling of existing data from WCA-3A to evaluate factors contributing to recent increases in phosphorus concentrations at the S-12's and S-333, including but not limited to changes in regulation schedule and apparent increases in inflow phosphorus loads from S-140 and S-9.

2. Assessment of factors responsible for recent increases in phosphorus concentration at S-12A, which were larger than those observed at other Shark Slough inflow structures.

3. An increased emphasis on composite sampling to track phosphorus concentrations and loads at monitoring sites in the L-31N/C-111 region, including sites on the mainstem canals, sites on eastern canals (C-102, C-103, C-113, C-11E), pump stations, and buffer/detention area overflow points.

4. Intensified monitoring of the L-31N/C-111 detention areas to support development of accurate water and phosphorus budgets, to assess the transport and fate of TP in surface and groundwater flows, and to support modeling of P dynamics.

5. Development and periodic updating of regional-average rainfall datasets for ENP, the WCA's, and contributing watersheds to support evaluation of future water quality and hydrologic trends in the context of background climatologic variations using methodologies similar to that employed in this report.

6. Continued refinement of the data and computation algorithms for tracking compliance with Consent Decree limits in the L-31N/C-111 basin. These refinements should consider changes in flow distribution and operation that influence P transport to ENP marshes in via surface flows and seepage, as well as the potential need for composite sampling to measure P fluxes at pump stations and other sites with highly dynamic flows that were not characteristic of the baseline period used to derive the limits.

7. Routine measurement of TP concentrations at S-335 to track P transport into the L-31N from the north.

8. It is recommended that a follow up, more sophisticated statistical analysis be carried out for selected constituents at some specified stations. The new analysis should identify and quantify the changes brought about by ISOP.

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**Appendix**

A-1   Table of Results

A-1. Table of Results.   All = 1994-2003; pre-IOP = 1994-1999; IOP = 2000-2003; Increase = IOP mean – pre-IOP Mean. % Increase = increase as percent of pre-IOP mean. SE = standard Error. R2 = regression model coefficient of determination. P = significance level, two-tailed test (* p < .15, ** p < .05)

Site	Variable	Units	Observed Values			Rainfall-Adjusted Values			Increase	Inc_SE	% Incr	%Inc_SE	R²	p
			All	pre-IOP	IOP	All	pre-IOP	IOP						
S150	Flow	kac-ft/yr	47.4	50.0	43.5	47.4	51.8	40.7	-11.1	15.0	-23%	29%	0.16	0.48
S150	Load	kg/yr	3231.6	3468.5	2876.2	3231.6	3466.9	2878.6	-588.3	1169.6	-17%	34%	0.04	0.63
S150	Conc	ppb	56.1	58.9	51.8	56.1	56.6	55.3	-1.3	10.0	-2%	18%	0.39	0.90
S150	FWMC	ppb	55.2	56.2	53.5	55.2	54.2	57.3	3.1		6%			
S140	Flow	kac-ft/yr	128.4	134.5	119.3	128.4	123.7	135.5	11.8	16.5	9%	13%	0.82	0.50
S140	Load	kg/yr	7925.6	6463.5	10118.8	7925.6	6033.8	10763.4	4729.7	1523.6	78%	25%	0.63	0.02 **
S140	Conc	ppb	53.7	40.4	73.6	53.7	42.5	70.5	28.1	12.2	66%	29%	0.59	0.06 *
S140	FWMC	ppb	50.0	38.9	68.7	50.0	39.5	64.4	24.9		63%			
G155	Flow	kac-ft/yr	82.0	111.9	37.3	82.0	102.0	52.2	-49.8	17.6	-61%	17%	0.86	0.03 **
G155	Load	kg/yr	19061.9	25379.8	9585.1	19061.9	22696.0	13610.8	-9085.1	4268.8	-40%	19%	0.86	0.07 *
G155	Conc	ppb	189.5	188.4	191.2	189.5	183.9	198.0	14.1	46.4	8%	25%	0.09	0.77
G155	FWMC	ppb	188.2	183.8	208.2	188.2	180.3	211.4	31.1		17%			
S190	Flow	kac-ft/yr	84.0	88.6	77.0	84.0	79.6	90.5	10.9	18.3	13%	23%	0.72	0.57
S190	Load	kg/yr	11734.2	13075.4	9722.4	11734.2	11647.4	11864.5	217.1	3759.3	2%	32%	0.62	0.96
S190	Conc	ppb	111.3	112.7	109.1	111.3	112.7	109.1	-3.6	20.2	-3%	18%	0.00	0.86
S190	FWMC	ppb	113.2	119.6	102.3	113.2	118.5	106.2	-12.3		-10%			
S8+G404	Flow	kac-ft/yr	337.2	373.8	282.4	337.2	346.5	323.3	-23.2	56.6	-7%	16%	0.74	0.69
S8+G404	Load	kg/yr	39359.9	44182.9	32125.6	39359.9	39794.5	38708.1	-1086.4	9430.8	-3%	24%	0.72	0.91
S8+G404	Conc	ppb	90.5	94.0	85.3	90.5	91.9	88.4	-3.5	15.5	-4%	17%	0.19	0.83
S8+G404	FWMC	ppb	94.5	95.7	92.2	94.5	93.0	97.0	4.0		4%			
S11X	Flow	kac-ft/yr	521.4	633.5	353.3	521.4	573.5	443.4	-130.1	74.1	-25%	13%	0.90	0.12 *
S11X	Load	kg/yr	16129.8	19828.4	10581.8	16129.8	18443.4	12659.4	-5784.0	1965.6	-31%	11%	0.90	0.02 **
S11X	Conc	ppb	25.5	27.7	22.3	25.5	27.9	21.9	-6.0	4.3	-22%	15%	0.22	0.21
S11X	FWMC	ppb	25.1	25.4	24.3	25.1	26.1	23.1	-2.9		-11%			
S9	Flow	kac-ft/yr	247.7	243.1	254.5	247.7	235.0	266.6	31.5	17.3	13%	7%	0.70	0.11 *
S9	Load	kg/yr	5244.5	4225.0	6773.7	5244.5	4090.7	6975.2	2884.5	788.4	71%	19%	0.66	0.01 **
S9	Conc	ppb	17.2	14.2	21.8	17.2	14.3	21.7	7.4	2.8	52%	20%	0.54	0.03 **
S9	FWMC	ppb	17.2	14.1	21.6	17.2	14.1	21.2	7.1		50%			
WCA-3A IN	Flow	kac-ft/yr	1448.2	1635.4	1167.3	1448.2	1512.2	1352.1	-160.1	113.8	-11%	8%	0.94	0.20
WCA-3A IN	Load	kg/yr	102687.6	116623.5	81783.6	102687.6	106172.6	97460.1	-8712.5	16076.4	-8%	15%	0.84	0.60
WCA-3A IN	Conc	ppb	56.1	56.9	54.9	56.1	56.3	56.0	-0.3	7.4	-1%	13%	0.09	0.97
WCA-3A IN	FWMC	ppb	57.4	57.8	56.8	57.4	56.9	58.4	1.5		3%			
S12A	Flow	kac-ft/yr	151.1	183.3	102.8	151.1	155.6	144.4	-11.2	38.9	-7%	25%	0.86	0.78
S12A	Load	kg/yr	1352.8	1412.6	1263.2	1352.8	1190.3	1596.6	406.3	315.0	34%	26%	0.84	0.24
S12A	Conc	ppb	8.1	6.9	10.0	8.1	7.0	9.8	2.8	0.8	40%	12%	0.72	0.01 **
S12A	FWMC	ppb	7.3	6.2	9.9	7.3	6.2	9.0	2.8		45%			
S12B	Flow	kac-ft/yr	136.7	155.0	109.2	136.7	133.9	140.9	7.0	28.0	5%	21%	0.87	0.81
S12B	Load	kg/yr	1137.1	1210.6	1027.0	1137.1	1048.6	1270.0	221.4	290.2	21%	28%	0.77	0.47
S12B	Conc	ppb	7.0	6.5	7.9	7.0	6.6	7.7	1.1	0.8	17%	12%	0.42	0.19
S12B	FWMC	ppb	6.7	6.3	7.6	6.7	6.3	7.3	1.0		15%			
S12C	Flow	kac-ft/yr	272.7	315.4	208.6	272.7	281.1	260.0	-21.1	34.5	-8%	12%	0.92	0.56
S12C	Load	kg/yr	2458.8	2723.5	2061.7	2458.8	2467.3	2445.9	-21.5	297.6	-1%	12%	0.90	0.94
S12C	Conc	ppb	7.9	7.4	8.6	7.9	7.6	8.3	0.7	0.7	10%	10%	0.56	0.35
S12C	FWMC	ppb	7.3	7.0	8.0	7.3	7.1	7.6	0.5		7%			
S12D	Flow	kac-ft/yr	333.7	396.2	240.0	333.7	353.9	303.5	-50.5	40.2	-15%	11%	0.93	0.25
S12D	Load	kg/yr	3691.4	4054.4	3147.0	3691.4	3684.7	3701.4	16.7	580.9	0%	16%	0.82	0.98
S12D	Conc	ppb	9.8	8.8	11.3	9.8	9.0	10.9	1.8	0.8	20%	9%	0.74	0.06 *
S12D	FWMC	ppb	9.0	8.3	10.6	9.0	8.4	9.9	1.4		17%			

A-1 Continued.

Site	Variable	Units	Observed Values			Rainfall-Adjusted Values			Increase	Inc_SE	% Incr	%Inc_SE	R²	p
			All	pre-IOP	IOP	All	pre-IOP	IOP						
S12X	Flow	kac-ft/yr	894.2	1049.9	660.6	894.2	924.5	848.7	-75.8	119.1	-8%	13%	0.93	0.54
S12X	Load	kg/yr	8640.1	9401.0	7498.8	8640.1	8390.9	9013.9	622.9	1222.5	7%	15%	0.88	0.63
S12X	Conc	ppb	8.5	7.7	9.8	8.5	7.9	9.4	1.5	0.7	19%	9%	0.69	0.08 *
S12X	FWMC	ppb	7.8	7.3	9.2	7.8	7.4	8.6	1.3		17%			
S333	Flow	kac-ft/yr	173.6	165.4	186.0	173.6	165.7	185.6	19.9	54.0	11%	33%	0.02	0.72
S333	Load	kg/yr	2644.4	2321.4	3129.1	2644.4	2345.2	3093.3	748.1	896.7	32%	38%	0.12	0.43
S333	Conc	ppb	12.3	11.2	13.9	12.3	11.3	13.7	2.3	0.8	20%	7%	0.73	0.02 **
S333	FWMC	ppb	12.3	11.4	13.6	12.3	11.5	13.5	2.0		18%			
S12X+S333	Flow	kac-ft/yr	1067.8	1215.3	846.6	1067.8	1090.2	1034.3	-55.9	106.9	-5%	10%	0.94	0.62
S12X+S333	Load	kg/yr	11284.6	11722.3	10627.9	11284.6	10736.1	12107.2	1371.1	1511.7	13%	14%	0.82	0.39
S12X+S333	Conc	ppb	9.3	8.3	10.8	9.3	8.6	10.4	1.9	0.6	22%	7%	0.82	0.02 **
S12X+S333	FWMC	ppb	8.6	7.8	10.2	8.6	8.0	9.5	1.5		19%			
NESRS	Flow	kac-ft/yr	150.5	155.1	143.6	150.5	156.6	141.4	-15.2	49.2	-10%	31%	0.02	0.77
NESRS	Load	kg/yr	2283.3	2099.5	2559.2	2283.3	2126.6	2518.5	392.0	883.6	18%	42%	0.05	0.67
NESRS	Conc	ppb	12.2	10.7	14.4	12.2	10.8	14.2	3.4	0.9	31%	9%	0.72	0.01 **
NESRS	FWMC	ppb	12.3	11.0	14.4	12.3	11.0	14.4	3.4		31%			
SRS_ENP	Flow	kac-ft/yr	1044.7	1205.0	804.3	1044.7	1081.1	990.2	-91.0	117.5	-9%	11%	0.93	0.46
SRS_ENP	Load	kg/yr	10923.5	11500.5	10058.0	10923.5	10517.5	11532.4	1014.9	1560.9	10%	15%	0.81	0.54
SRS_ENP	Conc	ppb	9.2	8.1	10.8	9.2	8.4	10.4	2.0	0.7	24%	8%	0.81	0.02 **
SRS_ENP	FWMC	ppb	8.5	7.7	10.1	8.5	7.9	9.4	1.6		20%			
L31N_IN	Flow	kac-ft/yr	91.7	60.4	138.6	91.7	62.9	134.9	72.0	18.9	79%	30%	0.74	0.01 **
L31N_IN	Load	kg/yr	1516.2	1039.0	2232.0	1516.2	1132.7	2091.5	958.8	406.1	85%	36%	0.66	0.05 *
L31N_IN	Conc	ppb	12.7	12.4	13.2	12.7	13.1	12.2	-0.9	2.4	-7%	19%	0.46	0.71
L31N_IN	FWMC	ppb	13.4	13.9	13.0	13.4	14.6	12.6	-2.0		-14%			
S174+S332D	Flow	kac-ft/yr	108.0	91.0	133.5	108.0	87.4	138.8	51.4	20.5	48%	23%	0.50	0.04 **
S174+S332D	Load	kg/yr	1246.2	1038.5	1557.9	1246.2	1027.2	1574.8	547.5	500.6	53%	49%	0.15	0.31
S174+S332D	Conc	ppb	9.0	8.9	9.1	9.0	9.1	8.9	-0.2	2.3	-2%	26%	0.07	0.93
S174+S332D	FWMC	ppb	9.3	9.2	9.5	9.3	9.5	9.2	-0.3		-3%			
S332+S175	Flow	kac-ft/yr	161.5	219.0	75.4	161.5	203.2	99.1	-104.1	58.4	-64%	29%	0.63	0.12 *
S332+S175	Load	kg/yr	1479.5	1982.0	725.8	1479.5	1858.4	911.2	-947.2	765.5	-51%	41%	0.41	0.26
S332+S175	Conc	ppb	6.9	7.1	6.7	6.9	7.2	6.5	-0.6	1.4	-8%	19%	0.05	0.68
S332+S175	FWMC	ppb	7.4	7.3	7.8	7.4	7.4	7.4	0.0		1%			
S176	Flow	kac-ft/yr	77.5	91.9	56.0	77.5	89.5	59.6	-29.9	16.4	-39%	18%	0.49	0.11 *
S176	Load	kg/yr	920.9	1124.6	615.2	920.9	1125.2	614.3	-510.9	473.9	-45%	42%	0.15	0.32
S176	Conc	ppb	9.1	9.6	8.3	9.1	9.8	8.1	-1.7	3.0	-18%	30%	0.06	0.58
S176	FWMC	ppb	9.6	9.9	8.9	9.6	10.2	8.3	-1.8		-18%			
S177	Flow	kac-ft/yr	132.8	136.7	127.0	132.8	131.1	135.4	4.3	23.4	3%	18%	0.39	0.86
S177	Load	kg/yr	1345.1	1146.8	1642.7	1345.1	1140.0	1652.9	512.9	408.9	45%	36%	0.19	0.25
S177	Conc	ppb	8.3	7.0	10.2	8.3	7.2	9.8	2.6	1.8	36%	25%	0.42	0.20
S177	FWMC	ppb	8.2	6.8	10.5	8.2	7.0	9.9	2.8		40%			
S18C	Flow	kac-ft/yr	186.3	199.8	166.1	186.3	190.4	180.3	-10.1	24.4	-5%	13%	0.65	0.69
S18C	Load	kg/yr	2339.3	2871.5	1541.0	2339.3	2615.7	1924.7	-691.0	881.5	-26%	34%	0.55	0.46
S18C	Conc	ppb	9.5	10.9	7.4	9.5	10.5	8.1	-2.4	2.6	-23%	25%	0.36	0.39
S18C	FWMC	ppb	10.2	11.6	7.5	10.2	11.1	8.7	-2.5		-22%			
S18C-S197	Flow	kac-ft/yr	155.9	165.3	141.7	155.9	158.4	152.0	-6.5	31.6	-4%	20%	0.37	0.84
S18C-S197	Load	kg/yr	1779.1	2129.3	1253.6	1779.1	1957.9	1510.8	-447.1	822.2	-23%	42%	0.39	0.60
S18C-S197	Conc	ppb	8.7	9.7	7.1	8.7	9.4	7.6	-1.8	2.4	-20%	26%	0.24	0.47
S18C-S197	FWMC	ppb	9.2	10.4	7.2	9.2	10.0	8.1	-2.0		-20%			

A-2   Monthly Time Series - Flow & Concentration
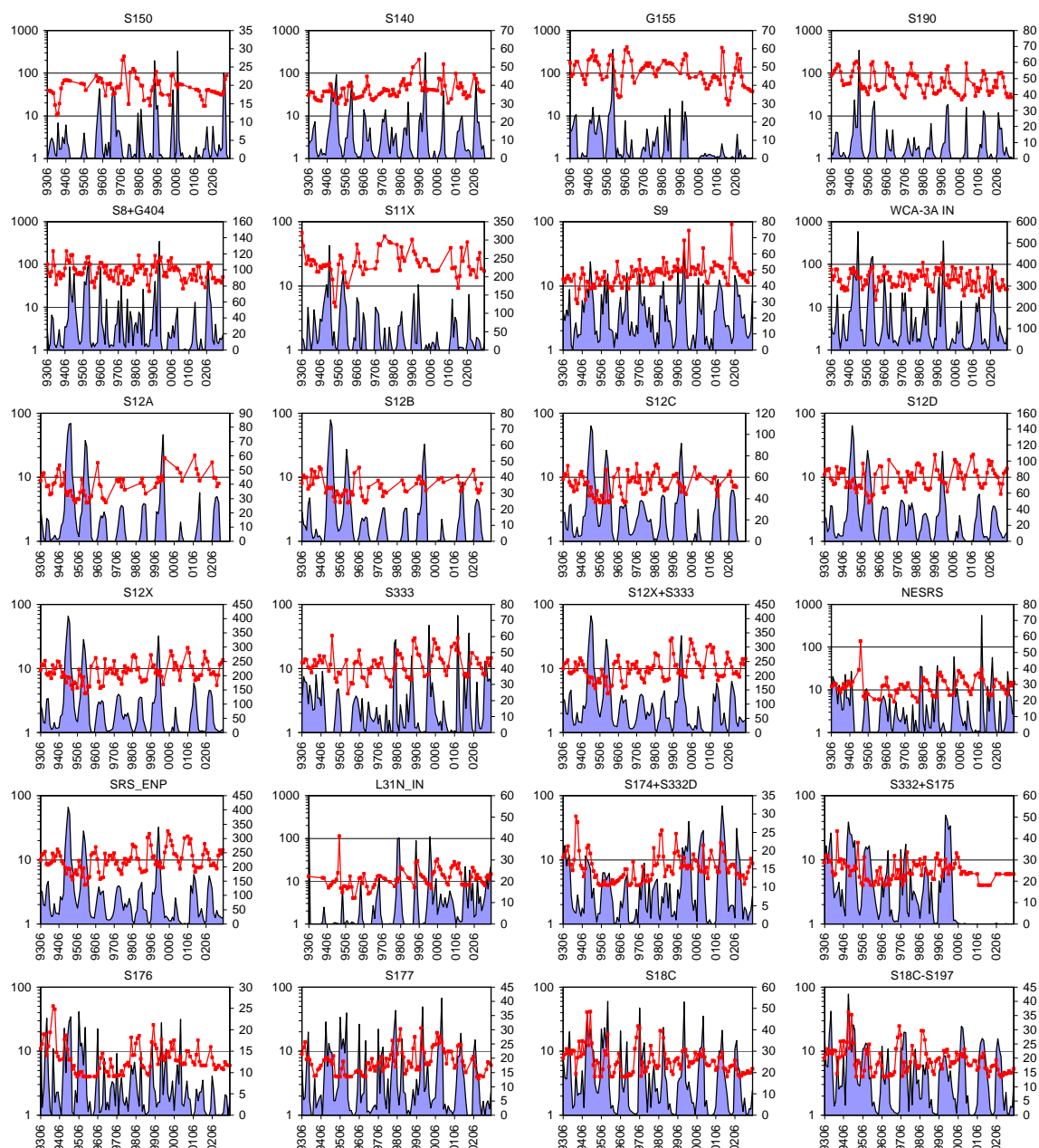

A-2 -   Monthly flows and concentrations.   Red lines / left axis = monthly flow-weighted mean TP concentration. Blue areas / right axis = flow (kac-ft/month)

A-3 Yearly Time Series -Flow & Concentration
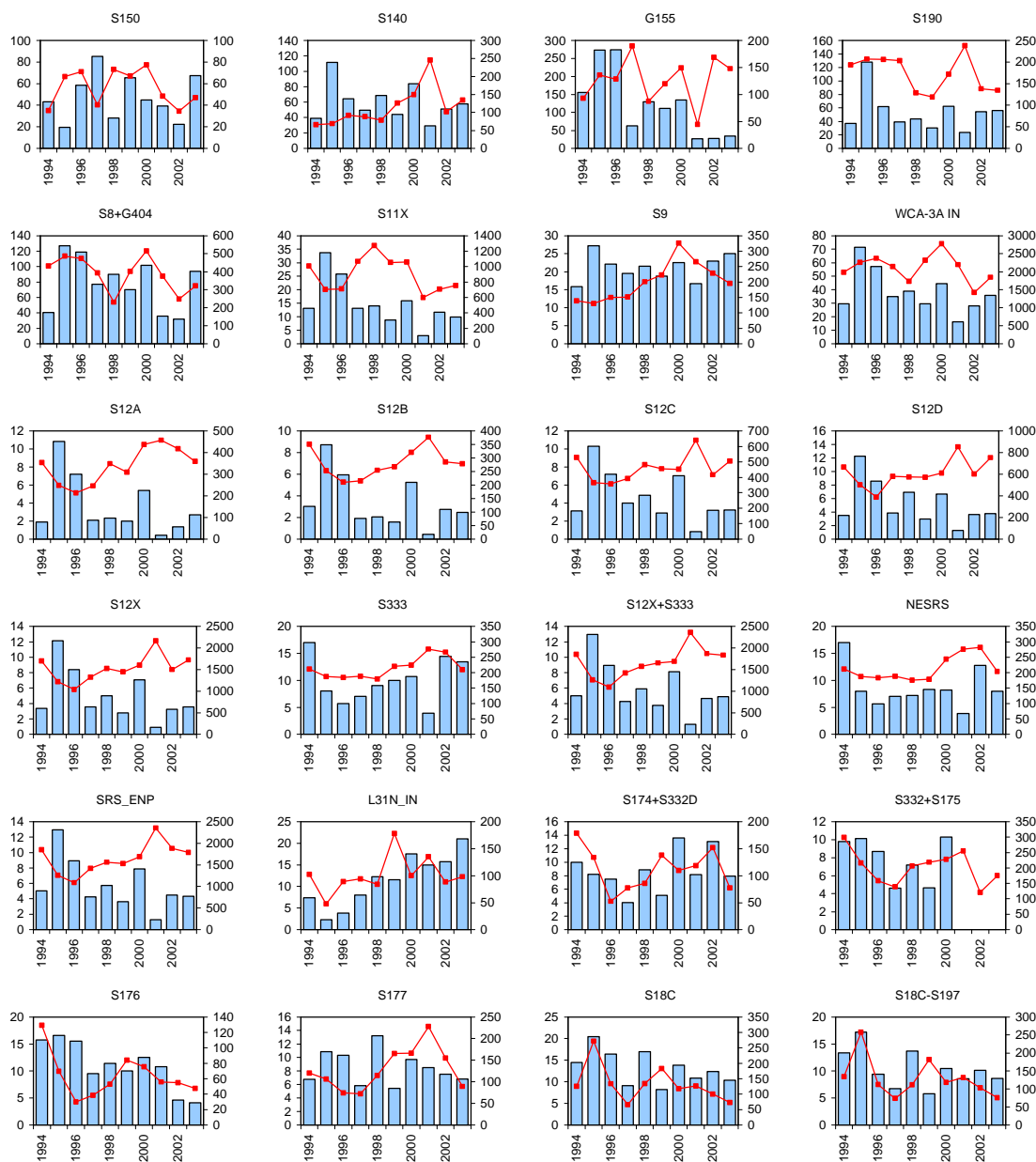
A-3.   Yearly flows and concentrations.   Red lines / left axis = yearly flow-weighted mean TP concentration. Blue bars / right axis = flow (kac-ft/yr). Water years 1994-2003.

A-4   Yearly Time Series – Load
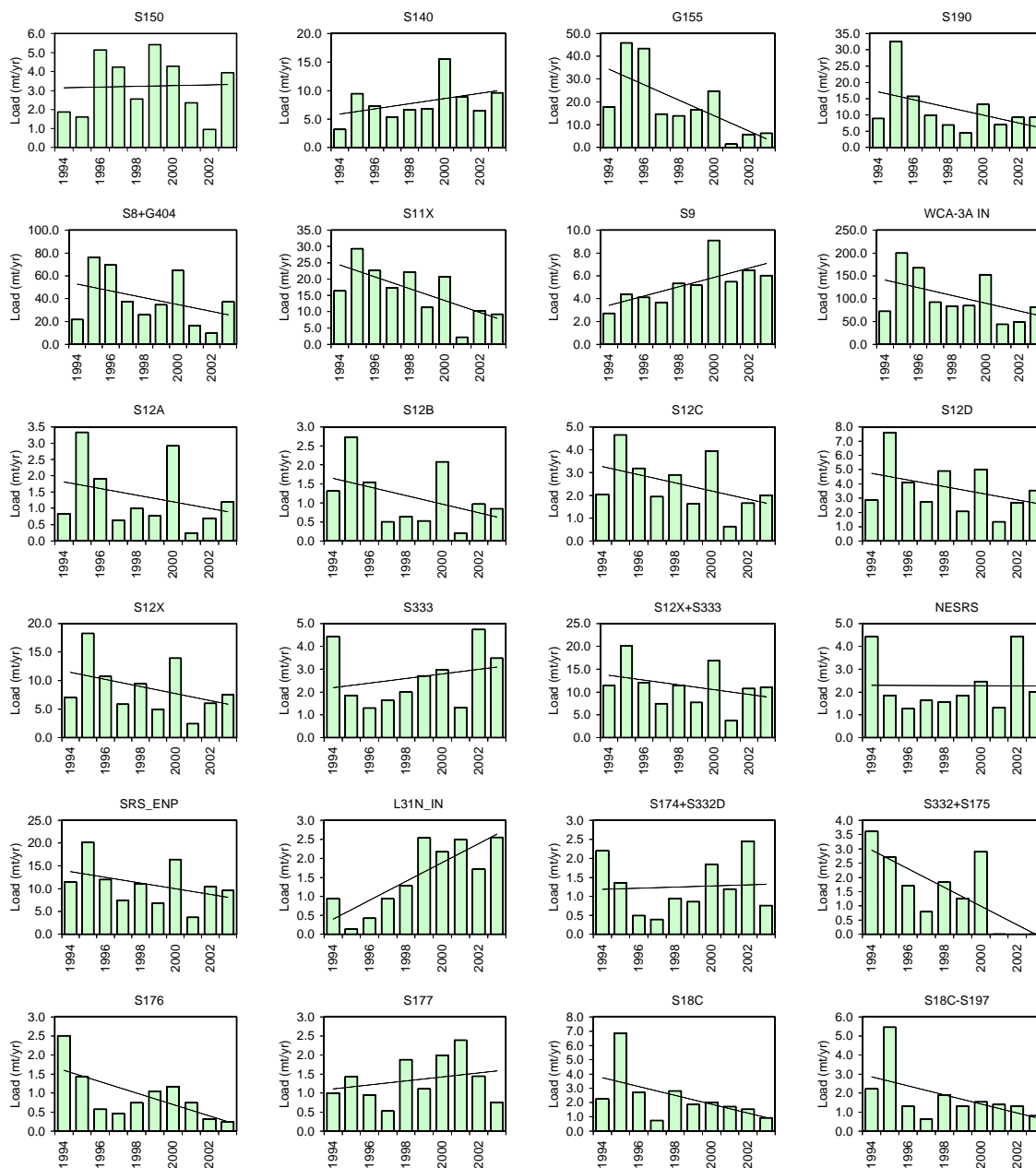
A-4. Yearly Total P loads.   Dotted line = linear trend. Water years 1994-2003.
Further details posted at http://www.wwwalker.net/iop